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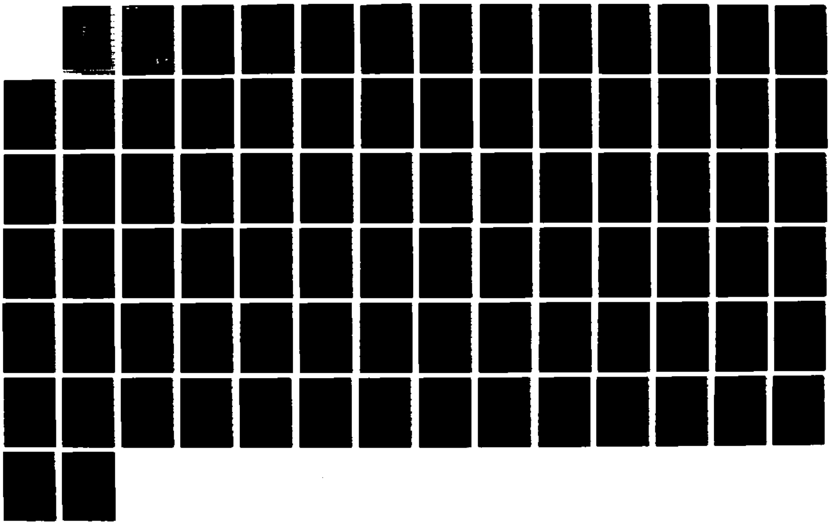

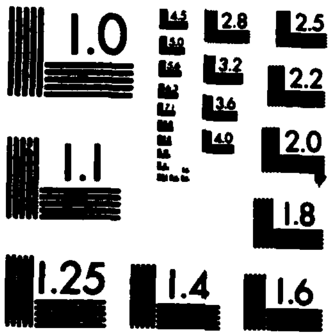

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ATMOSPHERIC STRUCTURE VARIATIONS

Modelling of Atmospheric Structure, 70 - 130 km

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MODELLING OF ATMOSPHERIC STRUCTURE, 70 - 130 km

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Theory and numerical analysis of data were applied to a number of leading problems of atmospheric structure in the upper mesosphere/lower thermosphere during the three years of this project. Three investigations occupied the first 18 months and concerned:

(1) Diurnal and semidiurnal tidal dissipation of momentum and energy in the upper atmosphere, (2) The modelling of O distribution from 85 km to the turbopause and (3) An empirical model for solar cycle changes in mesospheric structure.

During the second part of the project, attention was concentrated on:

(4) Atmospheric modelling of the intermediate region (70 - 130 km) between given models for the lower (up to 70 km) region and the upper (above 130 km) region. A preliminary report of this work, to the extent that it might meet the needs of a new COSPAR reference atmosphere, was presented at the 1986 COSPAR meeting and a detailed report of the theory and analyses was subsequently completed. (Continued overleaf)

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19. **ABSTRACT** (continued)

Summaries of the above four investigations are given as follows:

(1) Diurnal tidal momentum flux divergences agreed closely with the 1981 and 1984 evaluations of Miyahara up to 130 km but differed markedly above. Contributions from the semidiurnal tide were computed and were found to be comparable with those of the diurnal tide. Above 90 km, tidal heating was found to amount to 7% of radiational heating when averaged globally and at 70 - 90 km they were found to be comparable.

(2) A simple relation was presented for the vertical profile of the O/O_2 ratio from 85 to about 105 km which was consistent with detailed numerical calculation obtained by various authors for O distributions under conditions of vertical eddy diffusion and chemical removal in an otherwise static atmosphere. The relation presented shows the dependence of the O profile on a number of geophysical parameters.

(3) Formulae were presented for mesospheric temperature and pressure variations with sunspot number based on rocket temperature observations at longitudes 44 - 77° E. Resulting W - E wind variations were calculated by the geostrophic equation and found to have observational support. The formulae obtained were considered to be only tentative results, further observations, possibly by satellite radiance measurements, being needed at other longitudes to establish the global nature of the dependence. The formulae give results that differ from those obtained by Garcia (1984) by numerical computation of the mesospheric response to solar cycle changes.

(4) The modelling of neutral atmospheric structure in an intermediate height region (70 - 130 km) between given lower and upper models was treated theoretically and computationally. It was found that requirements to match both lower and upper (MSIS-86) models and observed temperatures at intermediate heights cannot be simultaneously satisfied. Examples of temperature, pressure and density tables for the 70 - 130 km height range were presented which were consistent with the observed temperatures up to 100 km but above 100 km observed temperature data consistently exceeded computed values with average differences reaching ~80 K at 115 - 120 km.

PUBLICATIONS

"Mean Zonal and Meridional Accelerations and Mean Heating Induced by Solar Tides for Equinox and Solstice Conditions," G.V. Groves and J.M. Forbes, Planet. Space Sci., 33, 282-293 (1985).

"The O/O_2 Ratio and Eddy Mixing at Heights from 85 km to the Turbopase," G.V. Groves, J. Atmos. Terr. Phys., 563-571 (1986).

"An Empirical Model for Solar Cycle Changes in Mesospheric Structure at Longitudes 44-77°E," G.V. Groves, Planet. Space Sci., 34, 1037-1041 (1986).

"Atmospheric Structure between 80 and 120 km," J.M. Forbes and G.V. Groves, Adv. Space Res., (1987).

1. Introduction

Season and latitude have traditionally featured as major dependences of the structure of the stratosphere and mesosphere. The Air Force Reference Atmospheres (Cole and Kantor, 1978) tabulated temperature, density and pressure for each month and each 15° N latitude to 90 km altitude. CIRA 1972, Part 2 tabulated these parameters for each month and each 10°N latitude to 110 km. Tabulations to 80 km at monthly intervals have been extended to the S hemisphere with a 10° latitude interval (Koshelkov, 1983; Barnett, 1984).

Additional dependences, notably local solar time and solar activity, are essential for modelling of the thermosphere as, for example, in CIRA 1972, Part 3 which extends upwards from 110 km. Further dependences are included in MSIS-83 (Hedin, 1983) which extends upwards from 90 km.

The present report addresses itself to the problem of modelling the intermediate region between mesospheric and thermospheric models. It seeks to develop a procedure for generating a smooth transition between selected lower and upper models in all relevant neutral atmosphere parameters including composition.

The need for improved modelling of the mesosphere/thermosphere region has long been evident and a 1984 recommendation for a new CIRA referred to the need for tabulations from 80 to 120 km. An altitude range from 70 to 130 km has been adopted for the present work to allow a smooth transition to be introduced to the lower and upper models, whose values are required to be matched at 70 and 130 km. The problem of modelling the 70 to 130 km region is therefore one of satisfying two types of conditions. One is imposed by the requirements of the upper and lower models and the other by the temperature data of the

intermediate region. Such data are taken in the present work at 5 km height intervals, i.e. at 75, 80,...,125 km. The problem is a novel one in atmospheric modelling in that the usual requirement is of the latter type, i.e. to obtain a fit to a set of data. In the present problem, the requirement to also match lower and upper models in all their relevant parameters is not an independent one and a particular matter of interest and concern is the extent to which both types of condition can be satisfactorily met. The treatment here is to rigidly match the lower and upper models (with continuity in the second height derivative) and at the same time optimise the fit to the intermediate temperature data, which may show a residual bias due to the rigid end constraints. In previous work (Forbes and Groves, 1986), data were found to be biassed higher than model values and the matter to warrant further consideration.

The procedure of model formulation is described in Appendix A and relates to the choice of MSIS-86 (Hedin, 1986) for the upper model and to that described in 'A Global Reference Atmosphere From 18 to 80 km' (Groves, 1985) for the lower model. A report of the earlier calculations undertaken at a preliminary stage of this work with MSIS-83 as the upper model has been given previously (Forbes and Groves, 1986). The subsequent stages then proposed for the formulation have now been completed and are reported here. These include (i) modelling of individual constituent gases and hence of total density and pressure, (ii) combining the three models for the height regions 18-70, 70-130 and above 130 km to provide a single model from 18 km upwards (Appendix D, Section 3), and (iii) the development of models for various solar conditions (and not only mean solar conditions as treated earlier).

2. Temperature data utilised, 70 to 130 km

Temperature data have been assembled from two earlier collations of data, i.e. from that used for the construction of CIRA 1972, Part 2 and the rocket and incoherent scatter (I.S.) data reviewed by Forbes (1984). Analyses of I.S. data from St. Santin (Alcaydé et al., 1979) have also been utilised.

I.S. temperatures were utilised as monthly means for the locations and heights shown in Table 1 and were compared with models computed for the solar activity parameters shown in the table.

Table 1. Distribution of available monthly mean I.S. temperatures.

Site	Height km	Solar activity $F_{10.7} = \bar{F}_{10.7}$	A_p
Millstone Hill (42 N) (Wand 1983, Table 1)	105-125	120	7
St. Santin (45 N) (Alcaydé et al., 1979, Table 1)	95-110, 120	70, 120, 170	7
Arecibo (18 N) (1970-75 data, Forbes 1984)	105-130	108	10

Monthly mean temperatures from rocket techniques were utilised for the locations and heights shown in Table 2. The Kwajalein data of 1976-78 have been compared with models computed for $F_{10.7} = \bar{F}_{10.7} = 95$ units. For the other data, which extend no higher than 100 km, solar effects are minimal and a value of $F_{10.7} = \bar{F}_{10.7} = 120$ units has been adopted for computing models for comparison purposes. Likewise a mean value of A_p (= 10) has been adopted in model computations.

Table 2. Distribution of monthly mean temperatures obtained by rocket techniques.

Site	Height km	Site	Height km
Heiss Is. (81 N)	75-100	Thumba (8 N)	75
Volgograd (48 N)	75-100	Ships (equator)	75-100
Kwajalein (9 N)	75-120	Molodezhnaya (68 N)	75-80

The locations at which single rocket profiles of temperature were utilised are shown in Table 3. The data available fall off rapidly above 100 km as shown in Table 3 by the numbers of profiles available at 105 and 120 km. Single profiles are compared with models computed for the same solar activity parameters as defined by the procedure described in Appendix B.

Table 3. Numbers of available temperature data at 105 and 120 km from rocket launchings.

Site	Height (km)		Site	Height (km)		Site	Height(km)	
	105	120		105	120		105	120
Pt Barrow (71 N)	3	0	Wallops (38 N)	18	16	Barking S (22 N)	3	0
Churchill (59 N)	8	5	White S (32 N)	8	0	Kwajalein (9 N)*	3	2
Sardinia (44 N)	0	1	Eglin (30 N)	6	1	Ascension (8 S)	2	0

* Developed into a monthly model (Cole et al., 1979) and listed in Table 2.

3. Model formulation, 70 to 130 km

The procedure devised for calculating a model temperature profile from 70 to 130 km is set out, step-by-step, in Appendix A. Theoretical details are presented in Appendices A1 to A5. An essential feature

of the method is the expression, for given geophysical conditions, of g/T (g being gravity acceleration and T temperature) as a polynomial in height whose coefficients are chosen (i) to give continuity up to the second height derivative with the lower and upper models, (ii) to reproduce, on integration of appropriate physical equations, the required ratio of N_2 pressure at 70 km to that at 130 km and (iii) to produce a best fit to observed temperatures at 75, 80,...,125 km altitude.

Appendix A sets out the step-by-step procedure for calculating density. The method is based on the MSIS-86 (Hedin, 1986) formulation for number densities of individual gas constituents. Other parameters then follow as set out in Appendix A.

4. Comparison of observed temperatures with models

This section analyses the differences between observed temperatures and model values computed in each case for the same geophysical conditions. Model values are derived by the procedure of Appendix A which involves polynomial coefficients a_{sn} whose determination depends on the analysis of temperature data as described in Appendix B.

Three cases with different selections of temperature data have been considered and a set of coefficients a_{sn} corresponding to the second of these cases is listed in Appendix B.

4.1 Case 1: a_{sn} based on all data excluding Millstone Hill

Case 1 was undertaken in the preliminary investigation (Forbes and Groves, 1986) which utilised all data at first and then excluded Millstone Hill data because of their relatively high values. The

comparisons reported in Sections 4.1.1 to 4.1.3 essentially repeat and update the results previously given.

4.1.1 At low latitudes

The first two columns of Table 4 show the average deviations from the computed models of temperature data from all months at Kwajalein (9 N) and Arecibo (18 N). Such deviations are denoted by x_i (for the i th site) in Appendix C which presents the relations used in the analysis. Kwajalein and Arecibo provide the main input of data above 100 km at low latitude and as previously noted (Forbes and Groves, 1986) the Kwajalein temperatures are (unexpectedly) lower than those of Arecibo by about 15 K on average.

An unsatisfactory latitude variation at low latitudes was modelled in the preliminary work (Forbes and Groves, 1986) by closely fitting to these data. The difficulty has been overcome in the present work by increasing the degree of smoothing to give models with an acceptable latitude structure at low latitude. The lower Kwajalein temperatures then lead to lower differences as shown for 105 - 120 km in Table 4.

In the last column of Table 4 are the mean values $(\bar{x})$, where the mean is taken over all sites appropriately weighted. The 11 means at 75,....,125 km are not significantly different from zero, having an average of 1 K (with 1 K standard deviation). A 1 K change over the height range 70 to 130 km is equivalent to a 4 per cent change in the ratio of N_2 pressures at 70 and 130 km. Such changes would be within the expected limits of accuracy and therefore the intermediate temperature data, taken as a whole over all sites, are not inconsistent with the lower and upper models. Data for a particular site may nevertheless still be biassed one way or the other with respect to the models, e.g. Arecibo data at 105 to 120 km show a region of bias to higher temperatures by about 10 - 20 K.

Table 4. Low latitude temperature differences from computed model values (K). Av = average difference for data of all months at a particular site. Case 1.

Height	Kwajalein		Arecibo		Ships (equator)		All sites*	
km	Av	sd	Av	sd	Av	sd	Mean of Av	sd
75	-1.4	1.3	-	-	-0.5	1.6	-0.5	1.7
80	2.4	0.8	-	-	-3.3	1.2	1.4	1.5
85	5.9	0.8	-	-	-6.5	1.0	1.8	3.2
90	6.9	0.7	-	-	-6.0	1.2	3.8	2.8
95	3.9	0.8	-	-	-1.7	2.1	3.3	1.7
100	-4.4	0.9	-	-	9.3	4.6	-3.5	2.6
105	-8.0	1.8	9.9	5.2	-	-	-3.5	13.0
110	1.4	1.3	13.9	5.6	-	-	2.1	3.5
115	10.3	3.9	23.0	6.1	-	-	14.0	8.2
120	-9.8	2.7	7.6	4.6	-	-	-5.3	10.7
125	-	-	-10.8	7.0	-	-	-10.8	7.0**

* Ascension Is. (8 S), Natal (6 S), Ships (equator), Kourou (5 N), Thumba (8 N), Kwajalein (9 N), Arecibo (18 N), Barking Sands (22 N), Carnarvon (25 S).

** Arecibo data only.

4.1.2 At middle latitudes

Table 5 presents average temperature differences from computed models for the 5 middle latitude sites that contribute most data at heights above 100 km. The mean of such averages with respect to all sites from 30° to 50° latitude is also shown. In contrast to the results of Table 4, model values are consistently lower than observed temperatures. Such a bias was noted and reported at the preliminary stage of this work (Forbes and Groves, 1986) and is able to arise as the least-squares fit is constrained by the requirement to match the N_2 pressures of the lower and upper models at 70 and 130 km.

If we consider the changes that would be needed in the models at 70 or 130 km to enable the intermediate model temperatures to fit observed values we find that either (i) pressures at 70 km would need to be lower by 40 per cent or (ii) pressures at 130 km would need to be higher by 40 per cent or (iii) corresponding partial adjustments would need to be made at both heights. Such pressure adjustments would require lower temperatures over some range of height in either or both of the lower and upper models thereby allowing higher values to be modelled in the intermediate region. The discrepancy between observed and model values is a matter of discussion in Section 7.

4.1.3 At high latitudes

Table 6 shows average temperature differences from computed models for three high latitude sites. Data are available from few sites at high latitude and then mainly below 105 km. As would be expected in these circumstances, no difficulty arises in deriving models that are consistent with the limited height range of available data.

Table 6 shows the mean of the average differences with respect to the few existing high latitude sites. The absence among these means of any significant difference from zero is a result of the paucity of data above 100 km.

Table 5. Middle latitude temperature differences from computed models (K). Av = average difference for data of all months at a particular site. Case 1.

Height	Eglin		White Sands		Wallops		St. Santin		Millst. Hill		All sites*	
km	Av	sd	Av	sd	Av	sd	Av	sd	Av	sd	Mean of Av	sd
75	-2	2	9	4	2	1	-	-	-	-	0.3	1.1
80	1	4	9	4	0	2	-	-	-	-	1.1	0.9
85	2	3	3	5	3	2	-	-	-	-	5.8	1.7
90	11	3	4	4	8	2	-	-	-	-	10.2	1.9
95	20	6	15	5	14	4	8	1	-	-	9.8	1.5
100	24	7	21	7	13	5	1	1	-	-	6.1	5.1
105	24	4	27	8	5	5	3	1	22	1	13.2	6.2
110	46	19	14	8	7	10	10	2	38	3	24.5	12.0
115	-	-	-	-	54	14	-	-	49	3	48.9	1.6
120	-	-	-	-	48	18	32	3	39	3	35.9	4.6
125	-	-	-	-	27	25	-	-	13	2	12.8	1.5

* Eglin (30 N), Woomera (31 S), White Sands (32 N), Arenosillo (37 N), Wallops (38 N), Millstone Hill (42 N), Sardinia (44 N), St. Santin (45 N), Volgograd (48 N), Kerguelen (49 S).

Table 6. High latitude temperature differences from computed models (K). Av = average difference for data of all months at a particular site. Case 1.

Height	Churchill		Pt. Barrow		Heiss Is.		All sites*	
km	Av	sd	Av	sd	Av	sd	Mean of Av	sd
75	3.6	1.6	-1.4	2.2	0.3	1.3	-1.4	3.1
80	-0.2	1.9	-0.4	2.4	0.6	1.8	-1.1	1.4
85	0.4	1.7	-0.2	3.0	0.7	1.6	0.5	0.4
90	5.8	3.1	6.7	2.8	-1.7	2.0	2.1	4.9
95	11.2	4.6	15.7	8.3	-5.8	2.7	-0.2	10.3
100	14.2	4.1	-7.6	13.1	-13.2	2.8	-4.6	15.4
105	12.0	7.4	-24.8	3.6	-	-	-17.8	20.5
110	6.0	13.3	-	-	-	-	6.0	13.3**
115	26.3	19.7	-	-	-	-	26.3	19.7**
120	47.3	32.3	-	-	-	-	47.3	32.3**
125	-	-	-	-	-	-	-	-

* Churchill (59 N), Molodezhnaya (68 S), Pt. Barrow (71 N), Heiss Is. (81 N).

** Churchill data only.

4.2 Case 2: a_{sn} determined without I.S. data and without data from 105 - 125 km

By excluding data above 100 km from the analysis of Appendix B and the determination of a_{sn}, we can expect to compute models that have a better fit to data at and below 100 km at the expense of having a poorer fit to the excluded data above 100 km. Comparisons between observed and computed temperatures are presented for the same groups of low, middle and high latitude sites as for Case 1. Data are much more numerous below 100 km than above and for this reason Case 2 is worthy of investigation.

4.2.1 At low latitudes

Table 7 presents the results for Case 2 corresponding to those for Case 1 in Table 4. As would be expected, model temperatures at 110 - 125 km are now lower (by ~ 10 K) and those at 85 - 100 km are higher (by ~ 2 K). These changes are generally significant for any particular site but over all sites the last columns of Tables 4 and 7 show that the changes in the means (which are also ~ 10 K and 2 K in the respective height ranges) are not significant, being of the same order of magnitude as the sd's of the means.

The fact that omission of data above 100 km results in such a limited change, on average, in the modelling accords with the conclusion of Section 4.1.1 that observed temperatures for 75 - 125 km are not inconsistent with the lower and upper models when taken as a whole over all sites.

For individual sites, the average differences between observed and computed temperatures may be significantly increased or decreased for Case 2 relative to Case 1. For Arecibo, observed values at 110 - 120 km are now higher than computed values by 30 - 40 K.

Table 7. Low latitude temperature differences from computed model values (K). Av = average difference for data of all months at a particular site. Case 2.

Height km	Kwajalein Av	Kwajalein sd	Arecibo Av	Arecibo sd	Ships (equator) Av	Ships (equator) sd	All sites* Mean of Av	All sites* sd
75	-1.3	1.3	-	-	-0.5	1.6	-0.4	1.7
80	2.5	0.8	-	-	-3.7	1.1	1.1	1.6
85	4.8	0.7	-	-	-7.5	0.9	0.4	3.2
90	4.2	0.5	-	-	-7.8	1.0	1.7	2.5
95	0.4	0.8	-	-	-3.6	1.8	-0.1	1.4
100	-7.1	1.0	-	-	8.1	4.3	-6.2	2.8
105	-8.0	1.9	9.3	5.7	-	-	-2.8	14.9
110	5.4	1.3	23.3	5.8	-	-	6.4	4.9
115	18.6	4.0	42.3	6.2	-	-	25.6	15.3
120	-0.7	2.7	29.9	5.3	-	-	5.6	17.5
125	-	-	-2.1	6.8	-	-	-2.1	6.8**

* Ascension Is. (8 S), Natal (6 S), Ships (equator), Kourou (5 N), Thumba (8 N), Kwajalein (9 N), Arecibo (18 N), Barking Sands (22 N), Carnarvon (25 S).

** Arecibo data only.

4.2.2 At middle latitudes

Table 8 presents average differences for Case 2 corresponding to Table 5 for Case 1. As expected the fit up to 100 km is much improved with both positive and negative average differences whose means over all sites are now not significantly different from zero (the last column of Table 8).

Above 100 km the high average differences of Table 5 become still higher for Case 2 being ~80 K at 115 - 120 km.

At middle latitudes, Cases 1 and 2 present straight choices between models that are biassed lower than observations at all heights, 75 - 125 km, (Case 1) and those that are biassed lower than observations at only 105 - 125 km (Case 2), the biasses nevertheless being significantly greater.

4.2.3 At high latitudes

Table 9 shows average differences at high latitude sites when data at 105 km and above are omitted from the determination of a_{sn}. At 110 km and above the omitted data amount to only 8 rocket temperature profiles at Churchill (59 N) and hence Table 9 shows no significant change from Table 6, being given here for the sake of completeness.

4.3 Case 3: a_{sn} determined without data at 75 - 95 km

In this case, all data at heights 100 - 125 km, including incoherent scatter data from Arecibo, Millstone Hill and St. Santin has been utilized for determining a_{sn} according to the procedure of Appendix B, while that below

Table 8. Middle latitude temperature differences from computed models (K). Av = average difference for data of all months at a particular site. Case 2.

Height	Eglin		White Sands		Wallops		St. Santin		Millst. Hill		All sites*	
km	Av	sd	Av	sd	Av	sd	Av	sd	Av	sd	Mean of Av	sd
75	-1	2	10	4	3	1	-	-	-	-	1.0	1.0
80	2	4	9	4	1	1	-	-	-	-	2.0	0.9
85	-2	3	-1	5	0	2	-	-	-	-	2.1	1.8
90	-1	3	-6	4	-3	2	-	-	-	-	-0.3	1.6
95	3	5	2	4	-1	4	-6	1	-	-	-2.9	2.0
100	11	7	11	6	1	5	-11	1	-	-	-5.7	5.3
105	23	4	26	8	4	5	1	1	21	1	13.8	6.0
110	62	19	28	9	25	10	23	2	53	2	42.4	12.8
115	-	-	-	-	91	14	-	-	80	3	80.8	2.9
120	-	-	-	-	90	17	65	3	75	3	69.9	6.3
125	-	-	-	-	45	25	-	-	27	2	27.2	1.7

* Eglin (30 N), Woomera (31 S), White Sands (32 N), Arenosillo (37 N), Wallops (38 N), Millstone Hill (42 N), Sardinia (44 N), St. Santin (45 N), Volgograd (48 N), Kerguelen (49 S).

Table 9 High latitude temperature differences from computed models (K). Av = average difference for data of all months at a particular site. Case 2.

Height	Churchill		Pt. Barrow		Heiss Is.		All sites*	
km	Av	sd	Av	sd	Av	sd	Mean of Av	sd
75	4.3	1.6	-1.2	2.2	0.2	1.3	-1.2	3.2
80	1.5	1.9	0.3	2.4	0.4	1.8	-0.3	1.4
85	0.4	1.7	0.0	3.0	0.6	1.6	0.4	0.2
90	1.9	3.0	5.9	2.8	-1.6	2.0	1.2	3.9
95	3.9	4.7	14.2	8.2	-5.3	2.7	-1.7	7.3
100	7.5	4.2	-9.3	13.1	-12.7	2.8	-6.6	11.3
105	9.4	7.6	-25.7	3.6	-	-	-19.3	19.2
110	10.8	13.6	-	-	-	-	10.8	13.6**
115	40.0	19.9	-	-	-	-	40.0	19.9**
120	64.3	32.1	-	-	-	-	64.3	32.1**
125	-	-	-	-	-	-	-	-

* Churchill (59 N), Molodezhnaya (68 S), Pt. Barrow (71 N), Heiss Is. (81 N).

** Churchill data only.

100 km has been omitted. In comparison with Cases 1 and 2 an improvement in the fit of computed temperatures to observed values can be expected above 100 km at the expense of lower computed temperatures and a poorer fit to observations below 100 km.

Table 10 shows the results obtained for mid-latitude data corresponding to Tables 4 and 7 for Cases 1 and 2. At 85 - 95 km, Table 10 shows that temperatures are ~20 K higher than model values. In comparison, the difference is ~10 K for Case 1, but differences above 100 km are greater. Case 2 produces a close fit at 85 - 95 km with still larger differences above 100 km.

5. Tabulations of temperature, pressure and density

A wide choice of options is open for the particular models to present as tables and for the format in which they are to appear. The choice involves the height interval of tabulation and many geophysical parameters.

Diurnal and zonal mean values have been tabulated in the course of this project as latitudinal-height cross-sections for solar activity parameters that are common with MSIS-86 tabulations, i.e. $F_{10.7}$ = 70, 150,230 units and A_p = 4, 48, 400.

Table 10. Middle latitude temperature differences from computed models (K). Av = average difference for data of all months at a particular site. Case 3.

Height	Eglin		White Sands		Wallops		St. Santin		Millst. Hill		All sites*	
km	Av	sd	Av	sd	Av	sd	Av	sd	Av	sd	Mean of Av	sd
75	0	2	12	4	5	1	-	-	-	-	2.6	1.2
80	10	4	20	4	11	2	-	-	-	-	10.8	1.0
85	16	3	19	5	19	2	-	-	-	-	20.3	1.7
90	23	3	18	4	23	2	-	-	-	-	23.4	1.9
95	25	5	21	5	22	4	16	1	-	-	18.5	1.6
100	19	7	17	7	10	5	-1	1	-	-	4.4	5.3
105	10	4	10	8	-12	5	-12	1	6	2	-6.5	5.7
110	23	18	-14	8	-23	9	-19	2	8	4	-2.4	14.1
115	-	-	-	-	19	12	-	-	13	4	13.3	2.6
120	-	-	-	-	23	16	6	4	13	4	9.9	5.3
125	-	-	-	-	22	25	-	-	6	1	5.9	1.3

* Eglin (30 N), Woomera (31 S), White Sands (32 N), Arenosillo (37 N), Wallops (38 N), Millstone Hill (42 N), Sardinia (44 N), St. Santin (45 N), Volgograd (48 N), Kerguelen (49 S).

Two formats have been adopted and coded (Appendix D, Section 3). One has a 5 km height interval (70 - 130 km) and 20^{o} latitude interval (80 S to 80 N) with 12 such tables per page consisting of temperature, pressure and density cross-sections for four selected months. Tables are presented in Appendix F for all months based on Case 2 determinations of a_{sn} and solar activity $F_{10.7}$ = 150 units, A_p = 4.

The second format has a 1 km height interval and 10^{o} latitude interval from 80 S to 80 N and is identical with the format previously used (Groves, 1985) for 18 - 80 km with each table occupying one page. The height range is from 65 to 135 km with the values at 65 - 70 km being those of the lower model and at 130 - 135 km being those of the upper model i.e. MSIS-86. This format is presented in Appendix F for January temperature, pressure and density cross-sections based on Case 2.

6. Limitations of the model formulation, 70 - 130 km

6.1 Types of data

The only type of data that has been utilized at heights 75 - 125 km is temperature, which has served both as an input to the formulation of the models for these heights and for comparison with the computed models to check their goodness-of-fit. A computed composition is available from the formulation, but compositional data have not been utilized either as an input to the formulation or to check against computed compositions.

6.2 Local solar time

No representation of tidal components at 70 - 130 km is included in the formulation. At 130 km, dependence on L.S.T. is that defined by MSIS-86 while, at 70 km, the lower model is independent of L.S.T. At intermediate

heights the L.S.T. dependence arises by interpolation while ignoring tidal fields that may have detailed spatial structures.

6.3 Longitude and solar activity effects

No detailed representation of longitudinal variations at 70 - 130 km is included in the formulation. At 70 and 130 km, the dependences on longitude are those of the adjacent lower and upper models and, relative to other variations at these heights, are very small. At intermediate heights, longitude dependence is then generated by interpolation and is a correspondingly small effect.

Dependence on solar activity is also not directly represented at heights between 70 and 130 km, but is present in the interpolation between these two heights where it is represented.

6.4 The coefficients a_{sn}

Sets of polynomial coefficients a_{sn} ($s = 1,\ldots,S$; $n = 1,\ldots,N$) are introduced by which height-latitude cross-sections of atmospheric structure parameters may be generated from 70 to 130 km at all latitudes. Subscript n is associated with a polynomial in height and subscript s with a polynomial in sin(latitude). Lack of data limits the number of sets of coefficients determined to 12, one for each month of the year. In principle, additional sets could be introduced with dependences on L.S.T., longitude and solar activity to help to overcome the limitations mentioned in Sections 6.2 and 6.3, but a vastly greater amount of data than that available would be required.

After many test computations with different choices of N and S, the choice was made of $N = 2$ and $S = 7$, giving 14 coefficients per set. Without improvements in the quality and quantity of available temperature profiles and

their latitude distribution, N and S could not be justifiably increased.

Since a_{sn} relate to a pole-to-pole representation, they provide a means of formulating seasonal asymmetries between N and S hemispheres. Unfortunately observations are not available for much of the S hemisphere and it becomes necessary to assume seasonal symmetry for latitudes where observations are lacking in the determination of a_{sn} (Appendix B).

7. Discussion

The modelling of atmospheric properties in an intermediate height region (70 - 130 km) between given mesospheric and thermospheric models has been treated theoretically (Appendices A, A1 to A5 and B) and computationally as summarised in Appendices D, E and F.

Temperature data (at 75, 80,..., 125 km) that are utilized for modelling the intermediate region are summarized in Section 2 and two formats, that have been devised for tabulating models of temperature, pressure and density, are outlined in Section 5 with examples given in Appendix F.

Section 4 presents comparisons between observed temperatures (75 - 125 km) and model values and is a Section that commands particular attention on account of biasses between the two which point to a possible inconsistency between the observed temperatures (75 - 125 km) and the given lower and upper models that are matched at 70 and 130 km. The biasses feature strongly at mid-latitudes, where the majority of available data have been obtained, and are in the sense that observed values are higher than model values (Case 1 and Table 5).

One way in which the discrepancy could be resolved would be by modifying the N_2 pressures of the lower and upper models at one or both of the heights

70 and 130 km. The magnitude of the discrepancy is such that its removal would require a 40 per cent change in the N_2 pressure ratio for these two heights and, as only as few per cent adjustment could reasonably be allowed at 70 km, the majority of it would need to be applied at 130 km.

Another possible conclusion is that observed temperatures are erroneously high over at least some part of the 70 - 130 km height region. Above 100 km, temperature data are provided by the I.S. technique and a small number of measurements by rocket techniques as summarised in Tables 1 to 3. Up to 100 km rocket data are much more numerous and are obtained by well-established techniques, such as the grenade experiment. Case 2 (Section 4.2) was therefore introduced to provide models that are consistent with the data at least up to 100 km (Table 8). The closer fit up to 100 km is however obtained at the expense of a poorer fit above 100 km as shown in Table 8, where biasses at 115 - 120 km are close to 80K for both I.S. measurements at Millstone Hill and St. Santin as well as rocket techniques at Wallops.

Support for high I.S. temperatures is provided by Arecibo data (18N) as shown in Table 7, where biasses at 115 - 120 km are about 30 - 40K, i.e. about half those at mid-latitudes. The presence of a small component of high energy electrons would give I.S. temperatures in excess of neutral gas temperatures and could possibly account for the discrepancy. The presence of a similar bias in the rocket measurements at Wallops (Table 8), which at 120 km amount to 16 in number (Table 3), means that the discrepency is unlikely to be solely attributable to biassed I.S. temperatures. In particular the possibility of adjusting to higher N_2 pressures at 130 km should be considered as by that means higher model temperatures at 115 - 120 km would result and reduce the discrepancy whatever the method of measurement.

Finally, the contrary view to that represented by Case 2 might be taken, namely that the inconsistency is attributable to observed temperatures below 100 km being too high. Case 3 therefore computes temperature models by fitting to data at and above 100 km only and in so doing generates values at 85 - 95 km that are on average $\sim$20 K lower than observed values (Table 10). At these heights, temperatures have been measured by the grenade, falling sphere and pitot pressure techniques, which are well-established methods that would not be expected to be consistently biassed by more than a few degrees K and certainly not by as much $\sim$20 K. Case 3 is not therefore considered to provide an acceptable model.

No positive recommendation for acceptable models of the intermediate (70 - 130 km) height range has been reached in the above investigations on account of consistent differences between temperature data and the possible models that can be computed with matching conditions at 70 and 130 km. One source of such differences between data and models could be the method of model formulation and the possibility of incompletely formulated dependences on L.S.T., longitude and solar activity is pointed out in Section 6. The differences, however, appear to have no consistent relationship with these dependences and are much greater in magnitude than any expected shortcomings in the formulation with respect to these dependences.

Attention therefore needs to be given to the possibility of observed values of temperature being overestimated. Case 2 has been devised to fit observed temperatures closely up to 100 km, but in so doing it provides models above 100 km that are less than observed mid-latitude values by

$\sim 80\,K$ at 115 - 120 km (Table 8) in order to match boundary conditions at 70 and 130 km. There may be scope for reducing the $\sim 80\,K$ difference at 115 - 120 km by revising MSIS-86 at 130 km - the region from 130 to, say, 150 km being poorly observed - but the general nature of the inconsistency, i.e. observed temperatures in excess of model values, would still remain.

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APPENDICES

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REFERENCES

1. Groves, G.V. A Global Reference Atmosphere From 18 to 80 km, Air Force Surveys in Geophysics, No. 448, AFGL-TR-85-0129, 31 May 1985.

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3. Groves, G.V. An Empirical Model for Solar Cycle Changes in Mesospheric Structure at Longitudes 44 - 77°E, Planet. Space Sci. 34, 1037 - 1041, 1986.

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APPENDIX A MODEL FORMULATION

1. Temperature

At height z in the range (z_1, z_2), where $z_1 \leqslant 80$ km (80 km being the upper limit of the lower model (1)) and $z_2 \geqslant 90$ km (90 km being the lower limit of the upper model (2)), we write

$$T = (M_{z_1} g / R) W \qquad (A.1)$$

where W is a function of height whose determination is the central consideration of the model formulation. g is acceleration due to gravity, R the universal gas constant and M_{z_1} the mean molecular weight of air as given by the lower model at height z_1.

As R may have (slightly) different values for any given lower and upper models and, likewise, g may be represented by different expressions in the two models, the values of R and g at height z are based on a smooth transition from R_1, $g_1(z)$ for the lower model to R_2, $g_2(z)$ for the upper model according to the relations

$$R = \tfrac{1}{2}\left[R_1 + R_2 + (R_2 - R_1) \tanh c\zeta \right] \qquad (-1 \leq \zeta \leq 1) \qquad (A.2)$$

$$g = \tfrac{1}{2}\left[g_1 + g_2 + (g_2 - g_1) \tanh c\zeta \right] \qquad (A.3)$$

where

$$c = 10 \qquad (A.4)$$

$$\zeta = (z - z_a)/z_d \; , \quad z_a = \tfrac{1}{2}(z_1 + z_2) \; , \quad z_d = \tfrac{1}{2}(z_2 - z_1) \qquad (A.5)$$

With c = 10, the accuracy at $\zeta = \pm 1$ is better than 1 in 10^{-8}. The lower and upper models provide:

$$M_{z_1} = 28.9644 \text{ kg}\,(\text{kmol})^{-1}, \quad R_1 = 8.31432 \times 10^3, \quad R_2 = 8.314 \times 10^3 \text{ J K}^{-1} (\text{kmol})^{-1} \qquad (A.6)$$

$$g_1 = g_\phi / (1 + z/r_\phi)^2 \quad \text{at latitude } \phi \qquad (A.7)$$

$$g_\phi = 9.780356\,(1 + 0.0052885\sin^2\phi - 0.0000059\sin^2 2\phi) \qquad (m s^{-2}) \qquad (A.8)$$

$$r_\phi = 2\times 10^3\, g_\phi \,/\, (3.08546 + 0.00227\cos 2\phi) \qquad (km) \qquad (A.9)$$

$$g_z = g_S \,/\, (1 + z/R_p)^2 \qquad (A.10)$$

where

$$g_S = 9.80665 \;\; m s^{-2} \;, \qquad R_p = 6356.77 \; km \qquad (A.11)$$

(It may be noted that, if the mean molecular weight of air is constant for $z \leq z_1$, W is pressure scale height (km) for $z \leq z_1$).

For $z_1 \leq z \leq z_2$, we express

$$W^{-1} = A + B \qquad (km^{-1}) \qquad (A.12)$$

where A and B are polynomials in ζ. B is an interpolating polynomial which depends only on conditions at height z_1 and z_2, as defined by the particular lower and upper models under consideration, and is otherwise independent of conditions relating to the interval (z_1,z_2). The conditions imposed at heights z_1 and z_2 are however such (see below) that B may be considered to provide a first approximation to W^{-1}.

A is an 'adjusting' polynomial whose determination is independent of conditions at heights z_1 and z_2 being dependent on temperature observations in (z_1,z_2) or more correctly on the differences between values of W^{-1} calculated by (A.1) from available temperature values and B calculated for the same geophysical conditions (of date, location, solar activity etc.).

We take A and its first two height derivatives to be zero at heights z_1 and z_2 by expressing it as

$$A = (1-\zeta^2)^3 \sum_{s=1}^{7} \sum_{n=1}^{2} a_{sn} (\zeta^n - \gamma_n)\, \zeta^{s-1} \quad ; \qquad \zeta = \sin\phi \qquad (A.13)$$

We choose $\gamma_1 = 0$, $\gamma_2 = 1/9$ as explained in Appendix A1. The determination

of a_{sn} is described in Appendix B, where values of a_{sn} are tabulated.

B is determined by 7 conditions involving model values at heights z_1 and z_2 and is therefore taken as a polynomial of degree 6 in ζ

$$B = b_1 + b_2\zeta + \ldots + b_7\zeta^6 = [1 \ \zeta \ \ldots \ \zeta^6]\, \underline{b} \qquad (A.14)$$

where $\underline{b} = [b_1 b_2 \ldots b_7]'$. Six of the conditions are for continuity of W^{-1} (and hence of T) and of its first and second height derivatives at heights z_1 and z_2. The seventh condition is that the ratio of the N_2 pressures at z_1 and z_2 as calculated from the model temperature profile should equal that of the N_2 pressures specified by the lower and upper models at z_1 and z_2. We write (Appendix A1)

$$\underline{b} = \underline{S}\,\underline{\ell} \qquad (km^{-1}) \qquad (A.15)$$

where

$$\underline{S} = \begin{bmatrix} 105 & -57 & -57 & -12 & 12 & -1 & 1 \\ 0 & -90 & 90 & -42 & -42 & -6 & 6 \\ -315 & 315 & 315 & 90 & -90 & 9 & 9 \\ 0 & 60 & -60 & 60 & 60 & 12 & -12 \\ 315 & -315 & -315 & -120 & 120 & -15 & -15 \\ 0 & -18 & 18 & -18 & -18 & -6 & 6 \\ -105 & 105 & 105 & 42 & -42 & 7 & 7 \end{bmatrix} \div 96 \qquad (A.16)$$

$$\underline{\ell} = [\ell_1 \ \ldots \ \ell_7]' \qquad (km^{-1}) \qquad (A.17)$$

For the conditions at height z_1, we have (Appendix A2)

$$\ell_2 = h_1 / D_1 + \Delta_1 \qquad (A.18)$$

$$l_4 = \left(D_2 / D_1^2 + \Delta_2 \right) z_d \qquad (A.19)$$

$$l_6 = \left[(D_1 D_3 + 2 D_2^2) / (h_1 D_1^3) + \Delta_3 \right] z_d^2 \qquad (A.20)$$

$$D_1 = 1 + q_1 \qquad (A.21)$$

$$D_2 = h_2 - q_2 \qquad (A.22)$$

$$D_3 = h_1 h_3 - 2 h_2^2 - q_3 \qquad (A.23)$$

$$h_r = \left[d^{r-1} (H_{ref}^{-1}) / d z^{r-1} \right]_{z_1} \qquad (r = 1, 2, 3) \qquad (A.24)$$

H_{ref} is the zonal mean pressure scale height of the lower model and hence from (A.24) and Ref. 1 we have

$$h_1 = \sum_{n=1}^{9} \sum_{s=1}^{9} c_{ns} \xi^{s-1} Z_1^{n-1}, \qquad \xi = \sin\phi \quad (km^{-1}) \qquad (A.25)$$

$$h_2 = \sum_{n=1}^{9} \sum_{s=1}^{9} (n-1) c_{ns} \xi^{s-1} Z_1^{n-2} / Z_d \qquad (km^{-2}) \qquad (A.26)$$

$$h_3 = \sum_{n=1}^{9} \sum_{s=1}^{9} (n-1)(n-2) c_{ns} \xi^{s-1} Z_1^{n-3} / Z_d^2 \qquad (km^{-3}) \qquad (A.27)$$

where

$$Z_1 = (z_1 - Z_a)/Z_d, \qquad Z_a = 48.75 \text{ km}, \quad Z_d = 31.25 \text{ km} \qquad (A.28)$$

and c_{ns} are linearly interpolated to the required date from the values tabulated in units of km^{-1} in Ref. 1. The dependence of l_2, l_4, l_6 on longitude, λ, is expressed by q_r, which by (A2.3) and (A2.7) is

$$q_r = K_{1r} \cos\lambda + L_{1r} \sin\lambda + K_{2r} \cos 2\lambda + L_{2r} \sin 2\lambda \qquad (A.29)$$

where, for j = 1,2; r = 1,2,3,

$$\begin{matrix} K_{jr} \\ L_{jr} \end{matrix} = k_1^r Y_r \,, \qquad Y_r = \left(d^{r-1} y / dz^{r-1} \right)_{z_1} \tag{A.30}$$

$$y = R_1 T_j \begin{matrix}\cos \\ \sin\end{matrix} \lambda_{Tj} / 10^3 M_{z_1} g_1 \qquad (\mathrm{km}) \tag{A.31}$$

Values of y are calculated from the values of T_j, λ_{Tj} tabulated in Ref. 1 for each month at 10^o latitude steps and are linearly interpolated to the required date and latitude. Y_r are obtained numerically from values $y_{-\frac{1}{2}}$, $y_{\frac{1}{2}}, y_{3/2}, y_{5/2}$ of y at 4 equally-spaced heights $z_{-\frac{1}{2}}, z_{\frac{1}{2}}, z_{3/2}, z_{5/2}$ of which z_1 is the mid-point and Δz is the increment step by fitting a cubic to provide

$$Y_1 = (9a_+ - b_+)/16 \tag{A.32}$$

$$Y_2 = (27a_- - b_-)/24\Delta z \tag{A.33}$$

$$Y_3 = (a_+ - b_+)/2(\Delta z)^2 \tag{A.34}$$

where

$$a_\pm = y_{3/2} \pm y_{1/2} \qquad b_\pm = y_{5/2} \pm y_{-1/2} \tag{A.35}$$

For the tabulations in Ref. 1, Δz = 4 km. For z_1 = 70 km (the value adopted), the 4 equally-spaced heights are 64,68,72 and 76 km. (For other values of z_1, (A.32) to (A.34) may need to be replaced by alternative formulae). The dimensions of q_r are $(\mathrm{km})^{-2(r-1)}$ for r = 1,2,3.

The terms Δ_r relate to incremental changes of temperature in the vicinity of height z_1 that may be associated with the solar cycle. Corresponding to a change ΔR_n in sunspot number from a reference value R_{no}, we have the formulation (Appendix A2)

$$\Delta_r = -K(\phi)\, \Phi_r\, \Delta R_n \qquad (r = 1, 2, 3) \tag{A.36}$$

where

$$K(\phi) = p + q \cos^n \phi \tag{A.37}$$

and

$$\Phi_1 = (1-\tau^2)(1+\alpha\tau^3) \tag{A.38}$$

$$\Phi_2 = \tau(1-\tau^2)(-2+3\alpha\tau-5\alpha\tau^3)/\ell \tag{A.39}$$

$$\Phi_3 = 2(1-\tau^2)[(1-3\tau^2)+\alpha\tau(3-16\tau^2+15\tau^4)]/\ell^2 \tag{A.40}$$

where

$$\tau = \tanh[(z_1-a)/\ell] \tag{A.41}$$

The quantities α,a,l,p,q and n are calculated from

$$\theta = \theta_1 + f\,\theta_2 \qquad (\theta = \alpha, a, l, p, q \text{ or } n) \tag{A.42}$$

$$f = \tanh(4\phi/\pi)\cos[\pi(t_d-1)/182.5] \tag{A.43}$$

t_d being the day number in the year. Numerical values for θ_1, θ_2 ($\theta = \alpha$,a,l,p,q or n) have been given (3) but are tentative being derived from limited data at eastern longitudes and therefore this dependence has only been included in exploratory calculations that are not a part of this report. The model of Ref. 1 is for data over years of average sunspot number, $R_{no} = 65$.

For the conditions at height z_2, we have (Appendix A3)

$$\ell_3 = 10^3 M_{3,1}\, g_2(z_2) / R_2 T(z_2) \tag{A.44}$$

where $T(z_2)$ is the temperature at height z_2 calculated from MSIS-86 for the required time, date, latitude, longitude, solar activity etc. Also

$$\ell_5 = -(2d+u)\,\ell_3\,z_d \tag{A.45}$$

$$\ell_7 = (6d^2 + 6ud + \eta)\,\ell_3\,z_d^2 \tag{A.46}$$

where

$$d = (R_p + z_2)^{-1} \qquad (km^{-1}) \tag{A.47}$$

For $z_2 \geqslant z_a = 117.2$ km

$$u = -\sigma_g\,[1 - T_\infty / T(z_2)] \qquad (km^{-1}) \tag{A.48}$$

$$\eta = u\,(2u + \sigma_g) \qquad (km^{-2}) \tag{A.49}$$

$$\sigma_g = \sigma\,[g_2(z_2)/g_2(z_\ell)] \qquad (km^{-1}) \tag{A.50}$$

where σ is taken from MSIS-86, being related to the MSIS-86 parameters of temperature T_ℓ and temperature gradient T'_ℓ at z_ℓ = 120 km and the MSIS-86 exospheric temperature T_∞ by $\sigma = T'_\ell/(T_\infty - T_\ell)$.

For $z_2 \leqslant z_a = 117.2$ km,

$$u = -2x_2\,T(z_2)\,(T_B + 2T_C x_2^2 + 3T_D x_2^4)\,(dx/dz)_{z_2} \tag{A.51}$$

$$\eta = 2T(z_2)\,(T_B + 6T_C x_2^2 + 15T_D x_2^4)\,(dx/dz)^2_{z_2} \tag{A.52}$$

where

$$x_2 = -[\xi(z_2, z_a) - \xi(z_0, z_a)] / \xi(z_0, z_a) \tag{A.53}$$

with

$$\xi(z, z_a) = (z - z_a)(R_p + z_a)/(R_p + z) \tag{A.54}$$

and

$$\left(\frac{dx}{dz}\right)_{z_2} = -\frac{1}{\xi(z_0, z_a)}\,\frac{g(z_2)}{g(z_a)} \tag{A.55}$$

The coefficients T_B, T_C, T_D are taken from MSIS-86 being related to the MSIS-86 parameters of temperature T_a and temperature gradient T'_a at $z = z_a$ and the MSIS-86 temperature T_o at height z_o of the MSIS-86 mesopause.

Finally, for the seventh condition, which involves values at both heights z_1 and z_2, we have (Appendix A4)

$$\ell_1 = (M_{z_1}/M_h)\, X / z_d \qquad (km^{-1}) \qquad (A.56)$$

where M_h = 28 kg/(kmol)$^{-1}$ and X is obtained by iteration (over only 2 or 3 cycles for 10^{-10} accuracy on taking an initial value of $X = (z_2-z_1)/(7km)$) from (A4.9) written as

$$X = (M_h/\bar{M}_0)\left[\ln \mu_{N_2} - A_{N_2}^{-1} \ln\left(1 + \nu_{N_2}^{A_{N_2}} e^{-X}\right)\right] \qquad (A.57)$$

where $\bar{M}_0$ = 28.95 kg(kmol)$^{-1}$ and

$$\mu_{N_2} = f_{N_2}\, p_1(z) / K(z_2)\, p_m(z_2, M_{N_2}) \quad ; \quad K(z_2) = 1.000292 \qquad (A.58)$$

$$\nu_{N_2} = n_d(z_2, M_{N_2}) / n_m(z_2, M_{N_2}) \qquad (A.59)$$

$$A_{N_2} = M_h / (\bar{M}_0 - M_{N_2}) \qquad (A.60)$$

where M_{N_2} = 28 kg(kmol)$^{-1}$. f_{N_2} is the N_2 fractional volume of air at height z_1 (= 0.78084) and $p(z_1)$, the air pressure at height z_1, is

$$p(z_1) = p_{ref}(z_1)\,(1 + D_0)(1 + \Delta_0) \qquad (A.61)$$

where $p_{ref}(z_1)$ is the zonal mean air pressure at height z_1 calculated from Ref. 1

$$p_{ref}(z_1) = \exp\left(-31.25 \sum_{n=0}^{9} \sum_{s=1}^{9} c_{ns}\, \xi^{s-1}\, 5^n/n\right) \qquad (mb) \qquad (A.62)$$

($5^n/n$ denoting unity for n = 0). c_{ns} are linearly interpolated to the required date from the values tabulated in Ref. 1. Dependence of $p(z_1)$ on longitude λ is introduced through

$$\mathcal{D}_0 = K_{10}\cos\lambda + L_{10}\sin\lambda + K_{20}\cos 2\lambda + L_{20}\sin 2\lambda \qquad (A.63)$$

where, for j = 1,2,

$$\begin{matrix} K_{j0} \\ L_{j0} \end{matrix} = (y)_{z_1}, \qquad y = p_j \begin{matrix} \cos \\ \sin \end{matrix} \lambda_{pj} \qquad (A.64)$$

Values of y are calculated from the values of p_j, λ_{pj} tabulated in Ref. 1 for each month and 10° latitude step and are linearly interpolated to the required date and latitude. The value of y at height z_1 is obtained by an interpolating cubic through four values $y_{-\frac{1}{2}}, y_{\frac{1}{2}}, y_{3/2}, y_{5/2}$ at heights $z_{-\frac{1}{2}}, z_{\frac{1}{2}}, z_{3/2}, z_{5/2}$ (as for Y_1 above), i.e.

$$(y)_{z_1} = (9a_+ - b_+)/16 \qquad (A.65)$$

where

$$a_+ = y_{3/2} + y_{1/2} \qquad b_+ = y_{5/2} + y_{-1/2} \qquad (A.66)$$

(For values of z_1 other than 70 km (the adopted value), (A.66) may need to be replaced by an alternative formula). Δ_0 is a relative pressure increase at height z_1 that may be associated with the solar cycle corresponding to (A.36), we have

$$\Delta_0 = K(\phi)\, \ell\, \Phi_0\, \Delta R_n \qquad (A.67)$$

where

$$\Phi_0 = 1 + \tau + \frac{\alpha}{4}(\tau^4 - 1) \qquad (A.68)$$

$n_d(z_2, M_{N_2})$, the N_2 diffusive profile number density, and $n_m(z_2, M_{N_2})$, the N_2 mixing profile number density, at height z_2 that appear in (A.59)

are MSIS-86 parameters that are calculated in units of cm^{-3} by the MSIS-86 formulation for the required time, date, latitude, longitude, solar activity, etc. In units of mb, we have

$$p_m(z_2, M_{N_2}) = 10^4 R_2 A_{N2}^{-1} n_m(z_2, M_{N_2}) T(z_2) \qquad (A.69)$$

where $T(z_2)$ is the MSIS-86 temperature at height z_2 for the required conditions and A_{N2}^{-1} is the reciprocal of Avogadro's number used in MSIS-86, i.e.

$$A_{N2}^{-1} = 1.66 \times 10^{-27} \qquad (kmol) \qquad (A.70)$$

Hence $A_{N2} = 6.02410 \times 10^{26}$ $(kmol)^{-1}$.

2. Density

At height z in the range (z_1, z_2) density ρ is calculated from

$$\rho = \sum_{i \neq 6} M_i \, n(z, M_i) / A_N \qquad (kg\,m^{-3}) \qquad (A.71)$$

where $n(z, M_i)$ is the number density (m^{-3}) at height z of gas constituent of molecular weight M_i, the values of M_i being taken to be those of MSIS-86, i.e. $M_1 = 4$, $M_2 = 16$, $M_3 = 28$, $M_4 = 32$, $M_5 = 40$, $M_7 = 1$ and $M_8 = 14$ corresponding to gases He, O, N_2, O_2, Ar, H and N. When different values of Avogardro's number are adopted for the lower and upper models, we take a smooth transition given by

$$A_N = \tfrac{1}{2}\left[A_{N1} + A_{N2} + (A_{N2} - A_{N1}) \tanh c\zeta\right] \qquad (-1 \leq \zeta \leq 1) \qquad (A.72)$$

where

$$A_{N1} = 6.02257 \times 10^{26} \qquad A_{N2} = 6.02410 \times 10^{26} \quad (mks\ units) \quad (A.73)$$

in the present calculation. For $n(z, M_i)$ we adopt the relations of the MSIS-86 formulation and have (Appendix A5)

$$n(z, M_i) = 10^6 \left[n_d(z, M_i)^{A_i} + n_m(z, M_i)^{A_i} \right]^{A_i^{-1}} C_{1i}(z)\, C_{2i}(z) \quad (m^{-3}) \qquad (A.74)$$

$$A_i = M_h / (\bar{M}_o - M_i) \qquad (A.75)$$

$$n_d(z, M_i) = n_d(z_2, M_i)\, e^{M_i J(\zeta)} \left[T(z_2)/T(z) \right]^{(1+\alpha_i)} \qquad (A.76)$$

$$n_m(z, M_i) = n_m(z_2, M_i)\, e^{\bar{M}_o J(\zeta)}\, T(z_2)/T(z) \qquad (A.77)$$

$$J(\zeta) = \left[U(1) - U(\zeta) \right] z_d / M_{z_1} \qquad (A.78)$$

$$U(\zeta) = \sum_{s=1}^{7} \sum_{n=1}^{2} a_{sn}\, \phi_n(\zeta)\, \zeta^{s-1} + b_1 \zeta + \tfrac{1}{2} b_2 \zeta^2 + \ldots + \tfrac{1}{7} b_7 \zeta^7 \qquad (A.79)$$

$$\phi_n(\zeta) = \zeta \left[\psi_1(\zeta, n) - \gamma_n\, \psi_2(\zeta) \right] \qquad (A.80)$$

$$(n = 1, 2)$$

$$\psi_1(\zeta, n) = \zeta^n \left(\frac{1}{n+1} - \frac{3\zeta^2}{n+3} + \frac{3\zeta^4}{n+5} - \frac{\zeta^6}{n+7} \right) \qquad (A.81)$$

$$\psi_2(\zeta) = 1 - \zeta^2 + \tfrac{3}{5} \zeta^4 - \tfrac{1}{7} \zeta^6 \qquad (A.82)$$

where $\alpha_i = -0.4$ for i = 1 and 7 (He and H) and is otherwise zero.

$C_{1i} = 1$ for N_2 (i = 3) and $C_{2i} = 1$ for He, N_2, O_2 and Ar (i = 1,3,4 and 5).

For the remaining cases

$$C_{ji}(z) = \exp\left\{ r_{ji} / \left[1 + \exp(z - z_{ji}) / H_{ji} \right] \right\} \qquad (j = 1, 2) \qquad (A.83)$$

$$r_{1i} = \tfrac{1}{2} \left[(R'_{1i} + R_{1i}) + (R_{1i} - R'_{1i}) \tanh c\zeta \right] \qquad (A.84)$$

$$r_{2i} = R_{2i} \qquad (A.85)$$

where

$$R_{1i} = \ln \left[\Omega_i\, n_m(z_\ell, M_{N_2}) / n_m(z_\ell, M_i) \right] \qquad (A.86)$$

The values of Ω_i, z_{ji}, H_{ji}, R_{2i} are those of MSIS-86 (Ref. 2, Table 2d) and for i = 2, 7 and 8 (O, H and N)

$$R'_{1i} = R_{1i} \qquad (A.87)$$

whereas for i = 1,4 and 5 (He, O_2 and Ar), R'_{1i} is chosen so that these

constituents have been given volume fractions of air, f_i, at height z_1. The required values are given by (Appendix A5)

$$R'_{1i} = \left[\!\left[\ln \mu_i - A_i^{-1} \ln \left\{ \left[\nu_i \, e^{M_i J(-1)} \left(T(z_2)/T(z_1) \right)^{\alpha_i} \right]^{A_i} + \left[e^{\bar{M}_0 J(-1)} \right]^{A_i} \right\} \right]\!\right] \times \left\{ 1 + \exp\left[(z_1 - z_{1i})/H_{1i} \right] \right\} \qquad (A.88)$$

$$p_m(z_2, M_i) = R_2 A_{N2}^{-1} n_m(z_2, M_i) T(z_2) \qquad (A.89)$$

$$\mu_i = f_i \, p(z_1) / \kappa(z_2) p_m(z_2, M_{N_2}) \qquad (A.90)$$

$$\nu_i = n_d(z_2, M_i) / n_m(z_2, M_i) \qquad (A.91)$$

for i = 1,4 and 5, where we take

$$f_1 (\equiv f_{He}) = 5.24 \times 10^{-6}, \quad f_4 (\equiv f_{O_2}) = 0.21023, \quad f_5 (\equiv f_{Ar}) = 9.34 \times 10^{-3}$$

$$\kappa(z_2) = \frac{8.31432 \times 6.02410}{6.02257 \times 8.314} = 1.000292 \qquad (A.92)$$

In order to maintain continuity in the mean molecular weight at height z_1, the value taken for f_{O_2} is such that the mean molecular weight of air at height z_1 for the gas constituents N_2, O_2, Ar, He is equal to M_{z_1}, i.e. such that $28 f_{N_2} + 32 f_{O_2} + 40 f_{Ar} + 4 f_{He} = M_{z_1}$ (= 28.9644). The value obtained, 0.21023, is slightly higher than the actual value, 0.20948, the excess being largely accounted for by the presence of CO_2 in the real atmosphere which is omitted in the model.

A useful check on computing accuracy is obtained by evaluating R'_{1i} for i = 3 (i.e. N_2) and comparing its value with the adopted value of zero.

3. Pressure

Total number density is obtained as

$$n = \sum_{n \neq 6} n(z, M_i) \qquad (m^{-3}) \qquad (A.93)$$

Mean molecular weight is then

$$\bar{M} = A_N \rho / n \qquad (kg\,(kmol)^{-1}) \qquad (A.94)$$

and pressure is

$$p = (R / A_N)\, n T \qquad (N m^{-2}) \qquad (A.95)$$

4. Turbopause height, z_{hi} of the i th gas constituent

In the MSIS-86 formulation, turbopause height is taken to be the height z_{hi} at which

$$n_m(z_{hi}, M_i) = n_d(z_{hi}, M_i) \qquad (A.96)$$

and z_{hi} is a fixed parameter, being 105 km for N_2, O_2, Ar, N and O, 100 km for He and 95 km for H. In the present formulation, where MSIS-86 parameters are adopted for the height z_2 which (at 130 km) exceeds the heights z_{hi}, the MSIS-86 values for z_{hi} cannot hold unless the derived temperature profile in (z_{hi}, z_2) is the same as the MSIS-86 profile, which clearly is not the case. However as deviations between the two profiles are not large, the values of z_{hi} satisfying (A.96) would not be expected to differ greatly from the MSIS-86 values. In the computations that have been undertaken the differences have been less than 1 km.

We calculate

$$z_{\ell i} = z_a + z_d\, \zeta_{\ell i} \tag{A.97}$$

where

$$\zeta_{\ell i} = \left\{ U(1) - \frac{z_d^{-1} M_{z_1}}{(\bar{M}_o - M_i)} \ln\left[\gamma_i \left(\frac{T(z_2)}{T(z_1)} \right)^{a_i} \right] \right\} \Big/ \left[U(\zeta_{\ell i}) / \zeta_{\ell i} \right] \tag{A.98}$$

The denominator in (A.98) is calculated from

$$\left[U(\zeta)/\zeta\right] = \sum_{s=1}^{7} \sum_{n=1}^{2} a_{sn} \left[\psi_1(\zeta, n) - \gamma_n \psi_2(\zeta) \right] \zeta^{s-1} + b_1 + \tfrac{1}{2} b_2 \zeta + \ldots + \tfrac{1}{7} b_7 \zeta^6 \tag{A.99}$$

ζ_{hi} is obtained from (A.98) by iteration with a suitable initial value (corresponding to say z_{hi} = 100 km).

APPENDIX A1 FORMULATION OF W^{-1}

We define

$$W^{-1} = A + B \qquad (-1 \le \xi \le 1; \; -1 \le \zeta \le 1) \quad (A1.1)$$

where, for given S, N and a_{sn} (which are independent of ξ and ζ)

$$A = (1-\zeta^2)^3 \sum_{s=1}^{S} \sum_{n=1}^{N} a_{sn} (\zeta^n - \gamma_n) \xi^{s-1} \quad (A1.2)$$

$$B = \sum_{r=1}^{7} b_r \zeta^{r-1} \quad (A1.3)$$

γ_n are chosen so that for all values of ξ

$$\int_{-1}^{1} A \, d\zeta = 0 \quad (A1.4)$$

Hence

$$\gamma_n = G_n / G_o \quad (A1.5)$$

where

$$G_n = \int_{-1}^{1} (1-\zeta^2)^3 \zeta^n \, d\zeta \quad (A1.6)$$

On integrating by parts it may be shown that

$$(n+7) G_n = (n-1) G_{n-2} \quad (A1.7)$$

Hence for n even

$$\gamma_n = (G_n / G_{n-2}) \ldots (G_2 / G_o)$$

$$= \frac{1.3 \ldots (n-3)(n-1)}{9.11 \ldots (n+5)(n+11)} \quad (n \text{ even}) \quad (A1.8)$$

For n odd, $G_1 = 0$ by direct evaluation and hence $G_3 = G_5 = \ldots = 0$ and

$$\gamma_n = 0 \qquad (n \text{ odd}) \quad (A1.9)$$

b_r are chosen so that for given $l_1, \ldots, l_7$, by (A1.1) to (A1.4),

$$\int_{-1}^{1} B\,d\zeta = \int_{-1}^{1} W^{-1}\,d\zeta = \ell_1 \qquad (A1.10)$$

$$B(-1) = W^{-1}(-1) = \ell_2\,, \quad \frac{dB(-1)}{d\zeta} = \frac{dW^{-1}(-1)}{d\zeta} = \ell_4\,, \quad \frac{d^2B(-1)}{d\zeta^2} = \frac{d^2W^{-1}(-1)}{d\zeta^2} = \ell_6 \qquad (A1.11)$$

$$B(1) = W^{-1}(1) = \ell_3\,, \quad \frac{dB(1)}{d\zeta} = \frac{dW^{-1}(1)}{d\zeta} = \ell_5\,, \quad \frac{d^2B(1)}{d\zeta^2} = \frac{d^2W^{-1}(1)}{d\zeta^2} = \ell_7 \qquad (A1.12)$$

These conditions require that

$$\underline{S}^{-1}\,\underline{b} = \underline{\ell} \qquad (A1.13)$$

where $\underline{b} = [b_1 \ldots b_7]'$, $\underline{\ell} = [\ell_1 \ldots \ell_7]'$ and

$$\underline{S}^{-1} = \begin{bmatrix} 2 & 0 & \frac{2}{3} & 0 & \frac{2}{5} & 0 & 2/7 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & -2 & 3 & -4 & 5 & -6 \\ 0 & 1 & 2 & 3 & 4 & 5 & 6 \\ 0 & 0 & 2 & -6 & 12 & -20 & 30 \\ 0 & 0 & 2 & 6 & 12 & 20 & 30 \end{bmatrix} \qquad (A1.14)$$

From (A1.13), we obtain

$$\underline{b} = \underline{S}\,\underline{\ell} \qquad (A1.15)$$

where, on inverting $\underline{S}^{-1}$

$$\underline{S} = \begin{bmatrix} 105 & -57 & -57 & -12 & 12 & -1 & 1 \\ 0 & -90 & 90 & -42 & -42 & -6 & 6 \\ -315 & 315 & 315 & 90 & -90 & 9 & 9 \\ 0 & 60 & -60 & 60 & 60 & 12 & -12 \\ 315 & -315 & -315 & -120 & 120 & -15 & -15 \\ 0 & -18 & 18 & -18 & -18 & -6 & 6 \\ -105 & 105 & 105 & 42 & -42 & 7 & 7 \end{bmatrix} \div 96 \qquad (A1.16)$$

APPENDIX A2 CONDITIONS AT HEIGHT z_1

By definition

$$W^{-1} = \frac{M_{z_1} g}{R T} = \frac{M_{z_1} g}{R T_{ref}} \frac{T_{ref}}{T(\lambda)} \tag{A2.1}$$

where the dependence of T on longitude λ is now indicated and T_{ref} denotes the zonal mean of $T(\lambda)$.

At height z_1, which is at or below 80 km, we have $R = R_1$, $g = g_1$ (as defined by (A.6) and (A.7)) and from Ref. 1, Appendix B

$$H_{ref}^{-1} = M_{z_1} g_1 / R_1 T_{ref} = \sum_{n=1}^{9} \sum_{s=1}^{9} c_{ns} \xi^{s-1} Z^{n-1} \tag{A2.2}$$

$$\Delta T = T(\lambda) - T_{ref} = T_1 \cos(\lambda - \lambda_{T1}) + T_2 \cos(2\lambda - \lambda_{T2}) \tag{A2.3}$$

where $\xi = \sin(\text{latitude})$, $Z = (Z - Z_a)/Z_d$, $Z_a = 48.75$ km, $Z_d = 31.25$ km and c_{ns}, T_1, T_2, λ_{T1}, λ_{T2} are tabulated in Ref. 1. Hence from (A2.1) to (A2.3)

$$W^{-1} = h_1 / D_1 \tag{A2.4}$$

where

$$h_r = d^{r-1}(H_{ref}^{-1}) / dz^{r-1} \qquad (r = 1, 2, 3) \tag{A2.5}$$

$$D_1 = 1 + q_1 \tag{A2.6}$$

$$q_r = h_1^r \left[d^{r-1}(R_1 \Delta T / M_{z_1} g_1) / dz^{r-1} \right] \qquad (r = 1, 2, 3) \tag{A2.7}$$

From (A2.4) and (A2.5)

$$\frac{dW^{-1}}{dz} = \frac{h_2}{D_1} - \frac{h_1}{D_1^2} \frac{dD_1}{dz} \tag{A2.8}$$

and from (A2.6) and (A2.7)

$$d\mathcal{D}_1/dz = (q_2 + h_2 q_1)/h_1 \tag{A2.9}$$

Combining (A2.8) and (A2.9) with the use of (A2.6) yields

$$d(W^{-1})/dz = \mathcal{D}_2 / \mathcal{D}_1^2 \tag{A2.10}$$

where

$$\mathcal{D}_2 = h_2 - q_2 \tag{A2.11}$$

From (A2.10) and (A2.11)

$$\frac{d^2 W^{-1}}{dz^2} = \frac{-2\mathcal{D}_2}{\mathcal{D}_1^3}\frac{d\mathcal{D}_1}{dz} + \left(h_3 - \frac{dq_2}{dz}\right)\frac{1}{\mathcal{D}_1^2} \tag{A2.12}$$

by (A2.5); and from (A2.6) and (A2.9)

$$d\mathcal{D}_1/dz = (\mathcal{D}_1 h_2 - \mathcal{D}_2)/h_1 \tag{A2.13}$$

while from (A2.5) and (A2.7)

$$dq_2/dz = (q_3 + 2h_2 q_2)/h_1 \tag{A2.14}$$

Hence (A2.12) to (A2.14) give, on using (A2.11)

$$d^2W^{-1}/dz^2 = (\mathcal{D}_1\mathcal{D}_3 + 2\mathcal{D}_2^2)/(h_1\mathcal{D}_1^3) \tag{A2.15}$$

where

$$\mathcal{D}_3 = h_1 h_3 - 2h_2^2 - q_3 \tag{A2.16}$$

The required conditions at height z_1, which are expressed by (A1.11), become by (A2.4), (A2.10), (A2.15) and (A.5)

$$\ell_2 = h_1 / D_1 + \Delta_1 \qquad (A2.17)$$

$$\ell_4 = (D_2 / D_1^2 + \Delta_2) z_d \qquad (A2.18)$$

$$\ell_6 = [(D_1 D_3 + 2D_2^2)/(\ell_1 D_1^3) + \Delta_3] z_d^2 \qquad (A2.19)$$

where h_r, q_r and D_r are evaluated at $z = z_1$ and the terms

$$\Delta_r = [d^{r-1}(\Delta W^{-1})/dz^{r-1}]_{z_1} \qquad (A2.20)$$

are introduced to enable an imposed change ΔW^{-1} of W^{-1} in the vicinity of $z = z_1$ to be taken into account due, for example, to a dependence on solar activity. Corresponding to an increase in temperature ΔT

$$\Delta W^{-1} = -W^{-1} T^{-1} \Delta T \qquad (A2.21)$$

A formulation has been given for ΔT corresponding to a change in sunspot number ΔR_n (3), by which (A2.20) and (A2.21) yield

$$\Delta_r = - K(\phi)\, \Phi_r\, \Delta R_n \qquad (A2.22)$$

$$K(\phi) = p + q \cos^n \phi \qquad (A2.23)$$

$$\Phi_r = \frac{d^{r-1}}{dz^{r-1}} \left[\frac{1 + \alpha \tanh^3 Z_s}{\cosh^2 Z_s} \right]_{z = z_1} \qquad (A2.24)$$

where

$$Z_s = (z - a)/\ell \qquad (A2.25)$$

The quantities α, a, ℓ, p,q and n are calculated from

$$\theta = \theta_1 + f\,\theta_2 \qquad (\theta = \alpha, a, \ell, p, q \text{ or } n) \qquad (A2.26)$$

$$f = \tanh(4\phi/\pi) \cos[\pi(t_d - 1)/182.5] \qquad (A2.27)$$

where t_d is the day number in the year and $\alpha_1 = 0.60$, $a_1 = 66.63$ km, $\ell_1 = 12.14$ km, $p_1 = 7.19 \times 10^{-5}$ km^{-1}, $q_1 = 4.80 \times 10^{-5}$ km^{-1}, $n_1 = 6.0$, $\alpha_2 = 0$, $a_2 = -3.09$ km, $\ell_2 = 0$, $p_2 = -0.51 \times 10^{-5}$ km^{-1}, $q_2 = -2.16 \times 10^{-5}$ km^{-1}, $n_2 = -5.0$.

APPENDIX A3 CONDITIONS AT HEIGHT z_2

At height z_2 ($\gg$ 90 km), MSIS-86 is valid and we have $R = R_2$, $g = g_2$ (as defined by (A.6) and (A.10)) and (A.1) becomes

$$W^{-1} = M_{z_1} g_2 / R_2 T \tag{A3.1}$$

By logarithmic differentiation

$$(W^{-1})^{-1} d(W^{-1})/dz = -2d - T^{-1} dT/dz \tag{A3.2}$$

where

$$d = 1/(R_p + z) \tag{A3.3}$$

A further differentiation gives, by (A3.3),

$$(W^{-1})^{-1} \frac{d^2W^{-1}}{dz^2} - (W^{-1})^{-2}\left(\frac{dW^{-1}}{dz}\right)^2 = 2d^2 + \left(\frac{1}{T}\frac{dT}{dz}\right)^2 - \frac{1}{T}\frac{d^2T}{dz^2} \tag{A3.4}$$

Hence from (A3.2) and (A3.4)

$$(W^{-1})^{-1}\frac{d^2W^{-1}}{dz^2} = 6d^2 + 4d\frac{1}{T}\frac{dT}{dz} + 2\left(\frac{1}{T}\frac{dT}{dz}\right)^2 - \frac{1}{T}\frac{d^2T}{dz^2} \tag{A3.5}$$

Different expressions hold for dT/dz, d^2T/dz^2 *according to whether* z *is* greater or less than z_a = 117.2 km.

For $z_2 \geq z_a$, we have (2)

$$T(z) = T_\infty - (T_\infty - T_\ell)\exp[-\sigma\xi(z, z_\ell)] \tag{A3.6}$$

$$\xi(z, z_\ell) = (z - z_\ell)(R_p + z_\ell)/(R_p + z) \tag{A3.7}$$

where T_∞ is exospheric temperature, T_ℓ is temperature at height z_ℓ (= 120 km) and R_p = 6356.77 km. σ is a constant that is related to

the temperature gradient, T_ℓ', at $z = z_\ell$ by $\sigma = T_\ell'/(T_\infty - T_\ell)$.

From (A3.6), we have

$$\frac{1}{T}\frac{dT}{dz} = -\sigma_g\left(1 - \frac{T_\infty}{T}\right) \qquad (A3.8)$$

$$\frac{1}{T}\frac{d^2T}{dz^2} = -\sigma_g\left(1 - \frac{T_\infty}{T}\right)\left[\frac{d}{dz}\left(\ln\frac{d\xi}{dz}\right) - \sigma_g\right] \qquad (A3.9)$$

where

$$\sigma_g = \sigma\, d\xi/dz \qquad (A3.10)$$

and from (A3.7), by (A.10) and (A3.3),

$$d\xi/dz = (R_p + z_\ell)^2/(R_p + z)^2 = g_2(z)/g_2(z_\ell) \qquad (A3.11)$$

$$\frac{d}{dz}\left[\ln\left(\frac{d\xi}{dz}\right)\right] = -2d \qquad (A3.12)$$

Hence if

$$u = -\sigma_g\left(1 - T_\infty/T\right) \qquad (A3.13)$$

$$\eta = u\,(2u + \sigma_g) \qquad (A3.14)$$

(A3.2) and (A3.5) give by (A3.8) to (A3.13)

$$(W^{-1})^{-1}\, dW^{-1}/dz = -(2d + u) \qquad (A3.15)$$

$$(W^{-1})^{-1}\, d^2W^{-1}/dz^2 = 6d^2 + 6ud + \eta \qquad (A3.16)$$

where by (A3.10) and (A3.11)

$$\sigma_g = \sigma\, g_2(z)/g_2(z_\ell) \qquad (A3.17)$$

For $z_2 \leq z_a$, we have (3)

$$T^{-1} = T_0^{-1} + T_B x^2 + T_C x^4 + T_D x^6 \qquad (A3.18)$$

where

$$x = -\left[\xi(z, z_a) - \xi(z_o, z_a)\right] / \xi(z_o, z_a) \qquad (A3.19)$$

$$\xi(z, z_a) = (z - z_a)(R_p + z_a)/(R_p + z) \qquad (A3.20)$$

z_o is mesopause height as determined by the MSIS-86 formulation. By (A3.18) we have

$$\frac{1}{T}\frac{dT}{dz} = -T\frac{dT^{-1}}{dz} = -2xT\left(T_B + 2T_C x^2 + 3T_D x^4\right)\frac{dx}{dz} \qquad (A3.21)$$

$$2\left(\frac{1}{T}\frac{dT}{dz}\right)^2 - \frac{1}{T}\frac{d^2T}{dz^2} = T\frac{d^2T^{-1}}{dz^2} = 2xT\left(T_B + 2T_C x^2 + 3T_D x^4\right)\frac{dx}{dz}\frac{d}{dz}\left[\ln\left(\frac{dx}{dz}\right)\right]$$
$$+ 2T\left(T_B + 6T_C x^2 + 15T_D x^4\right)\left(\frac{dx}{dz}\right)^2 \qquad (A3.22)$$

(A3.2) and (A3.5) can then be written, by (A3.19) to (A3.22) and (A3.3), as (A3.15) and (A3.16), where

$$u = -2xT\left(T_B + 2T_C x^2 + 3T_D x^4\right)\frac{dx}{dz} \qquad (A3.23)$$

$$\eta = 2T\left(T_B + 6T_C x^2 + 15T_D x^4\right)\left(\frac{dx}{dz}\right)^2 \qquad (A3.24)$$

and by (A3.19), (A3.20) and (A.10)

$$\frac{dx}{dz} = -\frac{1}{\xi(z_o, z_a)}\,\frac{g_2(z)}{g_2(z_a)} \qquad (A3.25)$$

The required conditions at height z_2, which are expressed by (A1.12), become by (A3.1), (A3.15) and (A3.16), on changing units from m to km in ℓ_3

$$\ell_3 = 10^3 M_{z_1} g_2(z_2) / R_2 T(z_2) \qquad (km^{-1}) \qquad (A3.26)$$

$$\ell_5 = -(2d + u)\ell_3 z_d \qquad (km^{-1}) \qquad (A3.27)$$

$$\ell_7 = (6d^2 + 6ud + \eta)\ell_3 z_d^2 \qquad (km^{-1}) \qquad (A3.28)$$

where d, u and η are evaluated at $z = z_2$.

APPENDIX A4 THE N_2 PRESSURE RATIO CONDITION

We adopt the MSIS-86 representation for the number density profile of a gas constituent, $n(z,M)$, as a meld of a diffusive profile $n_d(z,M)$ and a mixing profile $n_m(z,M)$. For molecular nitrogen, $M = M_{N_2}$ and the representation at $z = z_1$ is

$$n(z_1, M_{N_2})^{A_{N_2}} = n_d(z_1, M_{N_2})^{A_{N_2}} + n_m(z_1, M_{N_2})^{A_{N_2}} \qquad (A4.1)$$

where

$$A_{N_2} = M_h / (\bar{M}_o - M_{N_2}) \qquad (A4.2)$$

and $M_h = M_{N_2} = 28$, $\bar{M}_o = 28.95$ kg(kmol)$^{-1}$. On multiplying (A4.1) by $\left[(R_1/\mathcal{A}_{N1})T(z_1)\right]^{A_{N_2}}$, $R_1, \mathcal{A}_{N1}$ being defined by (A.6) and (A.73), we *obtain a relation in terms of the* N_2 *pressure* $p(z_1, M_{N_2})$ *at height* z_1

$$p(z_1, M_{N_2})^{A_{N_2}} = p_d(z_1, M_{N_2})^{A_{N_2}} + p_m(z_1, M_{N_2})^{A_{N_2}} \qquad (A4.3)$$

where

$$p_d(z, M_i) = (R/\mathcal{A}_N)\, n_d(z, M_i)\, T(z) \qquad (A4.4)$$

$$p_m(z, M_i) = (R/\mathcal{A}_N)\, n_m(z, M_i)\, T(z) \qquad (A4.5)$$

with $M_i = M_{N_2}$.

By integration of the hydrostatic equation, the diffusive and mixing pressures are

$$K\, p_d(z, M_i) = p_d(z_1, M_i)\, e^{-M_i I(z_1, z)} \left[T(z_1)/T(z)\right]^{\alpha_i} \qquad (A4.6)$$

$$K\, p_m(z, M_i) = p_m(z_1, M_i)\, e^{-\bar{M}_o I(z_1, z)} \qquad (A4.7)$$

where

$$I(z_1, z) = \int_{z_1}^{z} (g/RT)\, dz \qquad (A4.8)$$

$$K \equiv K(z) = (R_1/\mathcal{A}_{N1}) / \left[R(z)/\mathcal{A}_N(z)\right]$$

On dividing (A4.3) by $\left[p_m(z_2, M_{N_2})\right]^{A_{N_2}}$ we obtain, using (A4.4) to (A4.7) with $M_i = M_{N_2}$, $\alpha_i = 0$

$$\mu_{N_2} = e^{(\bar{M}_o/M_h)X}\left(\nu_{N_2}^{A_{N_2}} e^{-X} + 1\right)^{A_{N_2}^{-1}} \tag{A4.9}$$

where

$$X = M_h I(z_1, z_2) \tag{A4.10}$$

$$\mu_{N_2} = f_{N_2}\, p(z_1)/K(z_2)\, p_m(z_2, M_{N_2}) \tag{A4.11}$$

$$\nu_{N_2} = n_d(z_2, M_{N_2})/\, n_m(z_2, M_{N_2}) \tag{A4.12}$$

f_{N_2} is the N_2 volume fraction of air at height z_1 and $p(z_1)$ is air pressure at height z_1, which is evaluated as

$$p(z_1) = p_{ref}(z_1)\,(1 + D_c)(1 + \Delta_c) \tag{A4.13}$$

where p_{ref} is the zonal mean value for a reference value of solar activity (sunspot number) and D_o, Δ_o are relative incremental increases associated with longitude and sunspot number respectively. We have

$$D_o = \left[p(\lambda) - p_{ref}\right]/p_{ref} = p_1 \cos(\lambda - \lambda_{p1}) + p_2 \cos(2\lambda - \lambda_{p2}) \tag{A4.14}$$

where p_1, p_2, λ_{p1}, λ_{p2} are tabulated in Ref. 1. Corresponding to (A2.22)

$$\Delta_o = K(\phi)\, l\, \Phi_c\, \Delta R_n \tag{A4.15}$$

where

$$\Phi_o = \left[1 + \tanh Z_s + \tfrac{1}{4}\alpha\left(\tanh^4 Z_s - 1\right)\right]_{z=z_1} \tag{A4.16}$$

The required pressure ratio condition, which is expressed by (A1.10), is

$$l_1 = (M_{z_1}/M_h)\, X / z_d \tag{A4.17}$$

by (A.1), (A.5), (A4.8) and (A4.10).

APPENDIX A5 NUMBER DENSITIES

For a gas constituent of molecular weight M_i, the MSIS-86 representation of number density $n(z,M_i)$ introduces factors $C_{1i}(z)$, $C_{2i}(z)$ to account for effects of chemistry and flow:

$$C_{ji}(z) = \exp\{r_{ji}/[1+\exp(z-z_{ji})/H_{ji}]\} \quad (j=1,2) \qquad (A5.1)$$

$C_{1i} = 1$ for N_2 only ($i = 3$) and $C_{2i} = 1$ for all gases except O, H and N ($i = 2$, 7 and 8). The values adopted here for z_{ji}, H_{ji} ($j = 1,2$) and r_{2i} are those presented in MSIS-86 for all gases. So also are the values adopted here for r_{1i} ($i = 2$, 7 and 8) as these gases (O, H and N) are not required to match significant volume fractions of air at height z_1 (= 70 km). The other gases (He, O_2 and Ar) are however required to match significant volume fractions f_i ($i = 1,4$ and 5) at height z_1 and this is achieved by means of the relation

$$r_{1i} = \frac{1}{2}\left[(R'_{1i}+R_{1i})+(R_{1i}-R'_{1i})\tanh c\zeta\right] \qquad (A5.2)$$

valid for $z_1 \leq z \leq z_2$, where c and ζ are defined by (A.4) and (A.5). R'_{1i} depends on f_i and is derived as shown below. Values of R'_{1i} computed in this way are found to lie within about one per cent of R_{1i}. The adjustment using (A5.2) to provide a smooth transition between lower and upper models (for He, O_2 and Ar concentrations) is therefore of negligible physical consequence.

For the calculation of $n(z,M_i)$ we have (2)

$$n(z,M_i) = \left[n_d(z,M_i)^{A_i} + n_m(z,M_i)^{A_i}\right]^{A_i^{-1}} C_{1i}(z)\, C_{2i}(z) \quad (\mathrm{cm}^{-3})$$

$$(A5.3)$$

$$A_i = M_g / (\bar{M}_0 - M_i) \qquad (A5.4)$$

$$n_d(z, M_i) = n_d(z_2, M_i)\, e^{M_i J(\zeta)} [T(z_2)/T(z)]^{1+\alpha_i} \quad (cm^{-3}) \qquad (A5.5)$$

$$n_m(z, M_i) = n_m(z_2, M_i)\, e^{\bar{M}_0 J(\zeta)}\, T(z_2)/T(z) \quad (cm^{-3}) \qquad (A5.6)$$

where α_i is the thermal diffusion coefficient and by (A4.8), (A.1) and (A.5)

$$J(\zeta) \equiv I(z, z_2) = [U(1) - U(\zeta)] z_d / M_{z_1} \qquad (A5.7)$$

where

$$U(\zeta) = \int^{\zeta} W^{-1}\, d\zeta \qquad (A5.8)$$

By (A1.1) to (A1.3)

$$U(\zeta) = \sum_{s=1}^{S} \sum_{n=1}^{N} a_{sn} \phi_n(\zeta) \xi^{s-1} + b_1 \zeta + \tfrac{1}{2} b_2 \zeta^2 + \ldots + \tfrac{1}{7} b_7 \zeta^7 \qquad (A5.9)$$

$$\phi_n(\zeta) = \int^{\zeta} (1-\zeta^2)^3 (\zeta^n - \gamma_n)\, d\zeta = \zeta [\psi_1(\zeta, n) - \gamma_n \psi_2(\zeta)] \qquad (A5.10)$$

$$\psi_1(\zeta, n) = \zeta^n \left[\frac{1}{n+1} - \frac{3\zeta^2}{n+3} + \frac{3\zeta^4}{n+4} - \frac{\zeta^6}{n+7} \right] \qquad (A5.11)$$

$$\psi_2(\zeta) = 1 - \zeta^2 + \tfrac{3}{5} \zeta^4 - \tfrac{1}{7} \zeta^6 \qquad (A5.12)$$

To evaluate R'_{1i} ($i = 1, 4$ or 5) we note that $C_{2i} = 1$ ($i = 1, 4$ or 5) and put $z = z_1$ in (A5.3) to obtain, on multiplying through by

$(R_1/\mathcal{A}_{N1})\,T(z_1)/p_m(z_2,M_i)$ and using (A4.4) to (A4.7) and (A5.7),

$$\mu_i = \left\{ \left[\nu_i\, e^{M_i J(-1)\left(\frac{T(z_2)}{T(z_1)}\right)^{\alpha_1}} \right]^{A_i} + \left[e^{\bar{M}_o J(-1)} \right]^{A_i} \right\}^{A_i^{-1}} C_{1i}(z_1) \qquad \text{(A5.13)}$$

where

$$\mu_i = f_i\, p(z_1)/\,K(z_2)\, p_m(z_2, M_i) \qquad \text{(A5.14)}$$

$$\nu_i = n_d(z_2, M_i)/\,n_m(z_2, M_i) \qquad \text{(A5.15)}$$

By (A5.1) and (A5.13), we may solve for r_{1i} $(= R'_{1i})$, where

$$R'_{1i} = \left\{ 1 + \exp\left[(z_1 - z_{1i})/H_{1i}\right] \right\} \ln C_{1i}(z_1) \qquad \text{(A5.16)}$$

and

$$\ln C_{1i}(z_1) = \ln \mu_i - A_i^{-1} \ln\left\{ \left[\nu_i\, e^{M_i J(-1)\left(\frac{T(z_2)}{T(z_1)}\right)^{\alpha_i}} \right]^{A_i} + \left[e^{\bar{M}_o J(-1)} \right]^{A_i} \right\} \qquad \text{(A5.17)}$$

APPENDIX B METHOD OF DETERMINATION OF a_{sn}

We write (A1.2) as

$$\sum_{s=1}^{S}\sum_{n=1}^{N} C(s,n)\, a_{sn} = A \qquad (B.1)$$

where

$$C(s,n) = (1-\zeta^2)^2(\zeta^n - Y_n)\,\zeta^{s-1} \qquad (B.2)$$

and determine a_{sn} by the method of weighted least-squares from sets of values $C_k(s,n)$ ($s = 1,\ldots,S$; $n = 1,\ldots,N$), A_k for $k = 1,\ldots,K$. The weighting is based on estimated standard deviations of A_k, σA_k, which are obtained as described below.

The K sets of values are taken at grid points located on a meridional cross-section at each 5 km height interval from z_1 to z_2 (excluding the end points where $\zeta = \pm 1$ and no contribution is made to the determination of a_{sn}) and at each 10° latitude from pole to pole. Then

$$K = 19\left[(z_2 - z_1)/5 - 1\right] \qquad (B.3)$$

For the adopted values $z_1 = 70$ km, $z_2 = 130$ km, we have $K = 209$.

For each month, A_k are determined as the weighted average of differences

$$A = M_{z,\zeta}/RT - B \qquad (B.4)$$

where T is observed and B is calculated for the same geophysical conditions as the observation. When calculating B, the terms which introduce an observation's longitude and incremental sunspot number, ΔR_n,

into the lower model (as defined in Appendices A2 and A4) were found to be small and ineffective (in the a_{sn} determinations) and were therefore omitted in obtaining the a_{sn} values presented below. Longitude and solar activity dependences were however retained in the upper model (Appendices A3 and A4) in the calculation of B. Solar activity is expressed by the $F_{10.7}$, $\bar{F}_{10.7}$ and A_p indices which were assigned to the temperature data as follows:

(i) Time-averaged data

Incoherent scatter monthly means: Millstone Hill $A_p = 7$, $F_{10.7} = 120$; St. Santin $A_p = 7$, $F_{10.7} = 70$, 120, 170 (i.e. three sets of monthly means); Arecibo (1970 - 75) $A_p = 10$, $F_{10.7} = 108$ units.

Rocket monthly means: Kwajalein (1976 - 78) $A_p = 10$, $F_{10.7} = 95$; other sites (none of which provide data above 100 km) $A_p = 10$, $F_{10.7} = 120$ units.

$\bar{F}_{10.7}$ is the 3-month average of $F_{10.7}$ and was taken equal to $F_{10.7}$ for time-averaged data. ΔR_n (when not set equal to zero) is calculated from $F_{10.7}$ by

$$\Delta R_n = 1.08\, F_{10.7} - 62 - R_{no} \qquad (B.5)$$

where R_{no} is the reference sunspot number appropriate to the lower model and taken as 65.

(ii) Single rocket profiles

From the date of launch, R_n is calculated by linear interpolation of a table of monthly mean sunspot numbers, then

$$\Delta R_n = R_n - R_{no} \qquad R_{no} = 65 \qquad (B.6)$$

$$F_{10.7} = (R_n + 62) / 1.08$$

Likewise $\bar{F}_{10.7}$ is obtained from the 3-monthly sunspot number. A_p may be

specified for any launch or otherwise set equal to 10. Few profiles extend above 100 km at high latitudes (see Table 3) where dependence on A_p may be important. After examining A_p values for a sample of such launches, the approximation $A_p = 10$ for all launches appeared to be justified.

Dependence on local solar time in the upper model is included, when known, as in the case of single temperature profiles. For monthly mean temperature data, B is calculated for the diurnal mean upper model with the exception of incoherent scatter data which are obtained during daytime hours only. For I.S. data, B is evaluated for each hour between 0800 and 1600 hours and the average is taken of these 11 values.

The weighted average of the values of A calculated from (B.4) for the k th grid point is based on those temperatures at the height of the k th grid point that lie within 15^o latitude of the k th grid point and whose date of observation lies within 1.5 months of the middle of the given month. The weighting factor used in the averaging process is

$$\exp\left\{-\tfrac{1}{2}\left[(\Delta\phi/10)^2 + \Delta^2 m\right]\right\} \qquad (B.7)$$

where $\Delta\phi$ is the latitude displacement from the grid point (in degrees) and Δm is the date displacement (in months), $\Delta\phi/10$, Δm being less than 1.5. The most extreme data point to be included in the average is therefore at $\Delta\phi = 15^o$, $\Delta m = 1.5$ and has a weight of $e^{-2.25}$ (= 0.11) compared with a data point at the grid point ($\Delta\phi$ = m = 0) for which the weight is unity.

Temperature data are available either as single observations or as monthly mean values, but the relative accuracies of the various types of data are invariably unknown. The procedure adopted for assigning relative weights has been to weight all single profiles equally and to give all monthly means 3 times the weight of a single profile. A factor

of 10 (instead of 3) was initially adopted but this resulted in data for single profiles being almost completely discounted by that of the monthly means in cases where both were combined. The value of 3 was therefore adopted and seems to allow a more realistic utilisation of single profile data in the analysis. The final determinations of a_{sn} are not sensitive to the weights adopted as data for single profiles and monthly means are from different locations and tend not to combine.

The introduction of the weighting factor (B.7) results in fractional values for the weighted number of observations, N_w, and the minimum value for N_w below which the available temperature data are considered insufficient for the determination of A_k is taken to be 1.1. In that case A_k is taken to be the value of A_k for the same latitude in the opposite hemisphere with the month shifted by six months, if such a determination is possible with the data available. By this procedure, it was found that A_k could be determined at all grid points except for a number at high latitude (60^o or more) and above 100 km. For these grid points A_k is determined from (B.4) with T equal to its MSIS-86 value.

At the k th grid point, σA_k, the standard deviation of the weighted average A_k, is estimated from the standard deviation, σ, of the distribution of values of A in the average. The relation adopted is

$$\sigma A_k = \sigma / (N_w - 1.1)^{\frac{1}{2}} \qquad (B.8)$$

in which σ is also an estimated value. In those cases where A_k is found from MSIS-86 temperatures, σA_k is calculated as

$$\sigma A \equiv \sigma(M_{z,1}g/RT) = (M_{z,1}g/RT_c)(\sigma T/T_c) \qquad (B.9)$$

where T_c is the temperature value from CIRA 1972, Part 1 and

$$\log_{10}(\sigma T) = a(z - 67.5)/42.5 + b \qquad (B.10)$$

where a = 0.519, b = 0.617, (being values based on CIRA 1972 temperature distributions (4)). (B.10) gives σT = 4.4, 10.3, 24.0 K at 70, 100, 130 km respectively.

In those cases where σA_k can be found from (B.7), it was desirable to avoid unreasonably small values of σA_k which may at times arise with selective distributions of data. Hence σA_k is compared with σA and if found to be less than $\sigma A/3$, we take $\sigma A_k = \sigma A$.

The procedure for determining S and N in (B.1) is to take them as small as possible and consistent with a satisfactory least-squares fit to the values of A_k. The values chosen are S = 7, N = 2.

Sets of values of a_{sn} determined for each month for Case 2 of Section 4.2 are listed in Table B.1. Case 2 omits all data at and above 105 km in order to get an improved fit to data at 75 - 100 km. The number of grid points of the height-latitude cross-section used for the fit is 144, those omitted being at the five heights 105, 110,.., 125 km and at the 13 latitudes 60 S, 50 S,.., 50 N, 60 N. Grid points above 100 km at latitudes 70, 80, 90°N and S are retained so that the polynomial fit gives reasonable values at high latitudes above 100 km.

Case 3 which omits all data below 100 km in order to get an improved fit at 100 - 125 km utilizes grid points at 70, 80 and 90°N and S at all heights (75 - 125 km) so that the polynomial fit gives reasonable values at high latitudes. The number of grid points used for the fit is 133, 134 or 139 according to the month.

Table B.1 Coefficients a_{sn} calculated for Case 2.

COEFFICIENTS a11,...,a71; a12,...,a72

JANUARY	a11,...,a71 =	0.450239E+01	-0.401295E+01	0.410995E+01	0.248371E+02	0.871424E+00	-0.174643E+02	-0.135134E+02
	a12,...,a72 =	-0.522206E+01	0.435154E+01	0.799576E+01	-0.232239E+02	0.662491E+02	0.227469E+02	-0.775644E+02
FEBRUARY	a11,...,a71 =	0.471615E+01	-0.112349E+02	0.148038E+02	0.427365E+02	-0.254582E+02	-0.302905E+02	0.266413E+01
	a12,...,a72 =	-0.360527E+01	0.158603E+02	0.366494E+01	-0.425698E+02	0.860671E+02	0.263279E+02	-0.975830E+02
MARCH	a11,...,a71 =	0.439009E+01	-0.438530E+01	0.127738E+02	0.215197E+02	-0.158925E+02	-0.166991E+02	-0.532320E+01
	a12,...,a72 =	-0.479618E+00	0.632360E+01	0.875462E+01	0.417152E+01	0.701005E+02	-0.135413E+02	-0.915670E+02
APRIL	a11,...,a71 =	0.596443E+01	0.190373E+03	0.828147E+01	-0.679979E+00	-0.151203E+02	-0.137322E+01	-0.334064E+01
	a12,...,a72 =	0.129669E+01	0.124347E+02	0.312061E+02	-0.179300E+02	-0.168708E+02	0.312372E+01	-0.249716E+02
MAY	a11,...,a71 =	0.604768E+01	-0.457303E+03	-0.870562E+00	-0.716053E+01	0.572296E+01	0.433373E+01	-0.132484E+02
	a12,...,a72 =	0.869086E+00	0.137783E+02	-0.214193E+00	-0.410266E+02	0.743114E+02	0.218712E+02	-0.834851E+02
JUNE	a11,...,a71 =	0.617236E+01	0.168451E+01	0.117084E+01	-0.156581E+02	-0.274312E+01	0.922533E+01	-0.929290E+01
	a12,...,a72 =	-0.105801E+01	0.116203E+02	-0.591646E+01	-0.229524E+02	0.758758E+02	0.536377E+01	-0.779081E+02
JULY	a11,...,a71 =	0.542099E+01	0.334993E+01	-0.240554E+01	-0.226990E+02	0.148696E+02	0.162289E+02	-0.218331E+02
	a12,...,a72 =	-0.167619E+01	-0.526390E+01	-0.136329E+02	0.267299E+02	0.105370E+03	-0.268497E+02	-0.968885E+02
AUGUST	a11,...,a71 =	0.537040E+01	0.230382E+01	0.213179E+01	-0.133521E+02	0.404853E+01	0.141329E+02	-0.146901E+02
	a12,...,a72 =	-0.108923E+01	-0.739564E+01	-0.137024E+02	0.138464E+02	0.122689E+03	-0.118162E+02	-0.117580E+03
SEPTEMBER	a11,...,a71 =	0.499856E+01	-0.137003E+01	0.235666E+02	-0.816683E+01	-0.455914E+02	0.969329E+01	0.137220E+02
	a12,...,a72 =	0.804474E+00	0.117374E+01	-0.192181E+02	-0.213450E+02	0.135939E+03	0.228351E+02	-0.131212E+03
OCTOBER	a11,...,a71 =	0.540666E+01	-0.476904E+01	0.232597E+02	0.118278E+02	-0.564056E+02	-0.530451E+01	0.222247E+02
	a12,...,a72 =	0.269629E+01	-0.436791E+01	0.935034E+01	-0.229204E+01	0.275336E+02	0.852326E+01	-0.521826E+02
NOVEMBER	a11,...,a71 =	0.413789E+01	-0.436776E+01	0.299561E+02	0.230482E+02	-0.618755E+02	-0.116490E+02	0.247785E+02
	a12,...,a72 =	0.148522E+01	-0.120937E+03	-0.971447E+01	-0.524753E+01	0.967580E+02	0.714387E+01	-0.935975E+02
DECEMBER	a11,...,a71 =	0.315301E+01	-0.162521E+01	0.262781E+02	0.140383E+02	-0.528824E+02	-0.753700E+01	0.190181E+02
	a12,...,a72 =	-0.516278E+01	-0.721311E+03	0.217525E+02	-0.167133E+02	0.354254E+02	0.219389E+02	-0.598657E+02

APPENDIX C AVERAGE TEMPERATURE DEVIATIONS FROM MODEL VALUES AND THEIR MEAN WITH RESPECT TO DIFFERENT SITES

Comparisons between observed temperatures, T, and model values T_m are analysed in terms of the differences

$$T_d = T - T_m \qquad (C.1)$$

at each 5 km height interval. For the i th site we obtain the average deviation at any height as

$$x_i = \Sigma T_d / N_b \qquad (C.2)$$

where N_b is the number of observations available within a selected group of months. Four such groups are considered, namely (i) the three 'winter' months (DJF in the N hemisphere); (ii) the six 'equinox' months (MAMSON); (iii) the three 'summer' months (JJA in the N hemisphere); and (iv) all months. The standard deviation of x_i was estimated in each case as

$$\sigma x_i = \left[\Sigma (T_d - x_i)^2 / N_b (N_b - 1)\right]^{\frac{1}{2}} \qquad (C.3)$$

for $N_b \geq 2$.

The mean of x_i with respect to those sites for which a value of x_i could be determined was obtained as

$$\bar{x} = \sum_i w_i x_i / N_s \qquad (C.4)$$

where

$$w_i = N_s (\sigma x_i)^{-2} / \sum_i (\sigma x_i)^{-2} \qquad (C.5)$$

and N_s is the number of such sites.

The standard deviation of $\bar{x}$ was estimated as

$$\sigma \bar{x} = \sigma_D / (N_s - 2)^{\frac{1}{2}} \qquad (C.6)$$

where σ_D is the standard deviation of the distribution of the values, x_i, about $\bar{x}$, being estimated (for $N_s > 2$) from

$$\sigma_D^2 = \Sigma w_i (x_i - \bar{x})^2 / (N_s - 1) \qquad (C.7)$$

APPENDIX D CODING OF THE MODEL FORMULATION

In the course of this project Fortran programs have been written and tested for each stage of the model formulation and the work has proceeded to completion with the confidence that the formulation was computationally practical and efficient.

Over 50 programs have been developed, some of which are subprograms to the main calculation while others have served only a transient purpose. The latter category includes test programs (i.e. main programs for temporary use in the development and testing of the subprograms) and programs for one-off calculations such as the inversion of matrix (A1.14) and the calculation of Millstone Hill and St. Santin I.S. temperatures from formulae in the references quoted in this report.

The main programs will be described briefly in this Appendix to indicate some of the chief computational stages of the work.

Details of the subprograms and input files that are utilised in conjunction with these main programs are given in Appendix E. The particular way in which the computation breaks down into different subprograms reflects the stage-by-stage development of the method. No retrospective consideration has been given at the present time into restructuring the coding. Computational efficiency nevertheless appears to be quite good. All computations have been carried out interactively on EUCLID, (the GEC machine at University College London).

1. Determination of a_{sn} (Appendix B)

TDIFAVP4 (Temperature Differences Averaged Program 4) calculates A from (B.4) for each observed temperature at 5 km intervals and takes weighted averages to obtain A_k at each grid point of the height-latitudinal cross-section. σA_k is calculated by (B.8). When temperature data are lacking A_k is calculated from (B.4) for heights above 90 km using the temperature value of MSIS-86 and σA_k is used as a flag and set equal to zero.

(Note: the subprograms listed below need to be added to the main program in all cases. Subprograms that are already contained in a main program are not listed, being usually just short routines).

Subprograms: POLYZ12S, BCZ12S, BCATZ1S, BCATZ2S, EARTHS, GTS5S, MSISINS, SCATZ1S.

Input files: TPW12Q, COEFFDQ, RZDATA, THADATA, POLYTDD, DUMMYAXD.

Output files: TDIF(N_1), TDIF(N_1)Q, TD(N_1)SD.

(N_1) stands for an integer (the run number and is used to identify the outputs corresponding to different inputs).

$TDIF(N_1)$ contains A_k and σA_k; $TDIF(N_1)Q$ is an inspection file for output from the various stages of the computation; and $TD(N_1)SD$ contains the average temperature deviations from the fitted profile, x_i, and their standard deviations, σx_i, for the i th site at each 5 km height interval, the average being taken four times with respect to data falling in each of the groups of months (i) DJF, (ii) MAMSON, (iii) JJA and (iv) all months.

WADJP6 ($\underline{W}^{-1}$ <u>Adj</u>ustment <u>P</u>rogram <u>6</u>) obtains a_{sn} by weighted least-squares solution of (B.1) for each month of the year. Before doing this, it processes A_k and σA_k for each grid point of the height-latitudinal cross-section as described in Appendix B: (1) if A_k, σA_k have been calculated from observed temperature data they remain unchanged; (2) if $\sigma A_k = 0$ (i.e. data are lacking), A_k, σA_k are taken as the values for the grid point at the same latitude in the opposite hemisphere with a 6 month shift of date, unless this also has $\sigma A_k = 0$ (i.e. data are lacking there as well) when, at the original grid point, A_k is left unchanged (having been based on an MSIS-86 temperature) and σA_k is set equal to σA, the value calculated from (B.9); and (3) any σA_k which is less than $\sigma A/3$ is considered improbably small and is replaced by σA. WADJP6 is for Case 1 of Section 4.1.

<u>Subprogram</u>: NAG library routine F04ARF.

<u>Input file</u>: $TDIF(N_1)$

<u>Output files</u>: $OUTRN(N_1)$, $WADJ(N_1)D$.

$OUTRN(N_1)$ is an inspection file and $WADJ(N_1)D$ contains a_{sn}.

WADJP7 is WADJP6 modified to deal with Cases 2 and 3 of Sections 4.2 and 4.3.

2. Comparison of observations with derived model

TDIFAVP4 re-run. TDIFAVP4 is run as above with the following changes:

Input files: as before with DUMMYAXD replaced by WADJ(N_1)D.

Output files: TDIF(N_2), TDIF(N_2)Q, TD(N_2)SD.

Observed temperature data are now compared with the final model, calculated from (A.1), (A.12) and (A.13) using the determinations of a_{sn} which are read in from WADJ(N_1)D, whereas in the first use of TDIFAVP4 above a_{sn} were unknown and were read in as zeroes from DUMMYAXD. The purpose of this computation is to obtain TD(N_2)SD for x_i, σx_i for use with AVTDSDP8.

AVTDSDP8 (Average of mean Temperature Deviations and its Standard Deviation Program 8). For each site, the mean temperature deviations x_i from the model with respect to data taken in each of four groups of months, namely DJF, MAMSON, JJA and all year, and estimates of their standard deviations σx_i are read from TD(N_2)SD. The sites are put into three latitude groups, 0-30, 30-50, and 50-90°N or S and their summer, equinox, winter and all-year mean deviations are averaged and the standard deviations of these averages are obtained from equations (C.4) to (C.7). Results are shown in Tables 4 - 10 for the all-year mean deviations.

Subprograms: none

Input file: TD(N_2)SD.

Output file: AV(N_2)Q.

3. Tabulation of atmospheric properties at heights above 18 km

TVALP (Temperature Value Program) was written to develop a method for combining the outputs of the three models for the regions 18-70,

70-130 and above 130 km for given ranges of geophysical parameters (height, date, location, solar activity etc.). The program was first written for temperature only and later extended to provide composition, density and pressure. Five subprograms are included in this main program which generate particular outputs when flagged to do so:

TPDN for generating output of the height profiles of temperature and $\log_{10}$ of pressure, density and total number density at given height increments and their third differences with respect to height (to enable the smoothness of these profiles to be examined at 70 and 130 km where continuity in the second height-derivative has been formulated).

CHPARM for generating output of MSIS-86 diffusion and mixing number densities at 130 km, i.e. $n_d(z_2,M_i)$ and $n_m(z_2,M_i)$; MSIS-86 density parameter R_{1i} and the amended value R'_{1i} (equation A5.15); and turbopause height z_{hi} (equation A.96).

CHNUMD for generating output of $\log_{10}$ of the number density of gas constituents, $n(z,M_i)$, at given height increments and their third differences with respect to height (to enable the smoothness of these profiles to be examined at 70 and 130 km where continuity in the second height-derivative has beeen formulated).

ATMOS for generating output of temperature and of $\log_{10}$ of pressure, density, total number density and individual gas number densities.

ATMOSN for generating output of temperature, number density, total number, pressure and density.

Subprograms: TEMPS, POLYZ12S, BCZ12S, BCATZZS, BCATZ2S, SCATZ1S, EARTHS, MSISINS, LINES, GTS5S, CF1880S, CFZ1Z2S.

Input files: TPW12Q, COEFFDQ, WADJ(N_1)D, PARAMD.

Output file: TABLEQ.

TVAL1KMP (TVALP amended to give 1 km interval table Program). TPDN and CHNUMD are deleted from TVALP and changes are introduced in conjunction with two subprograms that are added:

TPDTB1 for generating output of separate temperature, pressure or density tables on each page of output with the same format and 1 km height interval as the corresponding tables in the report 'A Global Reference Atmosphere From 18 to 80 km' (Reference 1). Such tables appear in Appendix F.

POWER for use with TPDTB1 to calculate the power of 10 needed in the pressure and density tables.

Subprograms and Input files: as TVAL (but PRM86D1 replaces PARAMD).

Output file: TAB86Q1.

TVAL5KMP (TVALP amended to give 5 KM interval table Program). TVAL1KMP has subprogram TPDTB1 replaced by TPDTB5 and a few associated changes:

TPDTB5 for generating output of temperature, pressure and density tables with a 5 km height interval for each of four selected months such that these 12 tables fit into one page of output as shown in Appendix F.

Subprograms and Input files: as TVAL (but PRM86D5 replaces PARAMD).

Output file: TAB86Q5.

APPENDIX E MEMO LIST OF SUBPROGRAMS AND INPUT DATAFILES

COEFFDQ (Coefficients from part D of an earlier Q (standing for output)) is a datafile containing the coefficients c_{ns} for the lower model (Reference 1, pp. 108 - 109).

TPW12Q (Temperature, Pressure Waves 1 and 2 from an earlier Q) is a datafile containing the tables of amplitudes and phases of Ref. 1, pp. 110 - 121, which define the longitudinal dependences of temperature, pressure and density for the lower model. (Only the temperature and pressure dependences are utilized).

BCATZ1S (Boundary Conditions at height z_1 Subprogram) is

SUBROUTINE BCATZ1(ZZ,DAY,MN,GLAT,GLONG,G)

which is used with TDIFAVP4 (Appendix D) and interpolates coefficients c_{ns} of the 18 - 80 km region to the given day, DAY, of month, MN, and calculates the required conditions at latitude, GLAT, and height, ZZ (= z_1 = 70 km) transferring these values back to the calling program as G(1),...G(4) = $p(z_1, M_{N_2})$, 100 W^{-1} and the first two derivatives of $100 W^{-1}$ with respect to height at height z_1 according to the relations in Appendix A2. Longitude (GLONG) dependence is included unless ILONG1 is set equal to zero in the main program.

BCATZZS (Boundary Conditions at height z_1 or at lower height z Subprogram) is

SUBROUTINE BCATZZ(ZZ,DAY,MN,GLAT,GLONG,G)

which is used with TVALP, TVAL1KMP, TVAL5KMP (Appendix D) and is

BCATZ1S(ZZ,DAY,MN,GLAT,GLONG,G) with an additional section of instructions such that when ZZ = 70 it provides the same G(1),... G(4) as BCATZ1S and for other ZZ (= z) it provides G(1) = $p(z,M_{N_2})$ and G(2) = $100\,W^{-1}$ at height z (less than 70 km).

GTS5S is the MSIS-86/CIRA 1986 neutral atmosphere model of 15 March 1986 prepared by A.E. Hedin as

```
SUBROUTINE GTS5(IYD,SEC,ALT,GLAT,GLONG,STL,F107A,F107,AP,
                                                MASS,D,T)
```

with the additional facility to transfer parameters to other programs through the common block AA defined by

```
COMMON/AA/ DDF(8),DMX(8),HC04,HC16,BLK1,HC32,HC40,BLK2,HC01,
           HC14,ZC04,ZC16,BLK3,ZC32,ZC40,BLK4,ZC01,ZC14,BLK5,
           RC16,BLK6,BLK7,BLK8,BLK9,RC01,RC14,BLK10,HCC16,
           BLK11,BLK12,BLK13,BLK14,HCC01,HCC14,BLK15,ZCC16,
           BLK16,BLK17,BLK18,BLK19,ZCC01,ZCC14,RCU(8)
```

where DDF(I), DMX(I) are respectively the diffusion profile number density $n_d(z,M_I)$ and the mixing profile number density $n_m(z,M_I)$ corresponding to I = 1,2,3,4,5,7,8. RCU(I) are likewise the values of R_{1i} (Appendix A5).

BCATZ2S (Boundary Conditions at height z_2 Subprogram) is

```
SUBROUTINE BCATZ2(IYD,SEC,Z2,GLAT,GLONG,STL,F107A,F107,AP,G)
```

which calls GTS5 to calculate the MSIS-86 conditions required at height z_2 (= 130 km) and transfer them to the calling program as G(1),...G(6) = $p_m(z_2,M_{N_2})$, $p_d(z_2,M_{N_2})$, $100\,W^{-1}$ and the first three derivatives of $100\,W^{-1}$ with respect to height at height z_2 according to the relations in Appendix A3. (G(6) is not utilized).

BCZ12S (Boundary Conditions at z_1 and z_2 Subprogram) is

```
SUBROUTINE BCZ12(Z1,Z2,IDAY,MN,GLAT,GLONG,SLT,F107A,F107,
                                                AP,G1,G2)
```

and is the calling program of (1) either BCATZ1 (if used with TDIFAVP4) or BCATZZ (if used with TVALP, TVAL1KMP or TVAL5KMP) to obtain G(I) as G1(I) to which the sunspot number dependent changes are applied by calling SCATZ1 and (2) BCATZ2 to obtain G(I) as G2(I).

SCATZ1S (Solar Cycle at height z_1 Subprogram) is

SUBROUTINE SCATZ1(ZZ,IYD,GLAT,RNDEL,GDEL)

which calculates incremental values GDEL(I) arising from an incremental change of sunspot number RNDEL according to the relations (A2.22) and (A4.15).

RZDATA (Sunspot number, R_z, Datafile) contains monthly mean sunspot numbers from January 1957 to January 1972, the interval of time within which the launch dates of single rocket profiles fall.

POLYZ12S (Polynomial coefficients for height range z_1 to z_2 Subprogram) is

SUBROUTINE POLYZ12(Z1,Z2,IDAY,MN,GLAT,GLONG,SLT,F107A,F107,AP,B)

which calculates the polynomial coefficients $\underline{b}$ from (A1.15) having first obtained $\underline{\ell}$ which involves the relations of Appendix A4 to obtain ℓ_1 from (A4.17).

EARTHS (Earth radius and gravity Subprogram) is

SUBROUTINE EARTH(ALAT,GEPHI,RPHI)

which calculates g_ϕ and r_ϕ from (A.8) and (A.9) at latitude ALAT ($=\phi$).

MSISINS (MSIS variations included Subprogram) is

SUBROUTINE MSISIN

which lists those of the 23 variations of MSIS-86 that are being

omitted when the Subroutine GTS5 is called.

THADATA (Temperature high altitude Datafile) contains observed temperatures at 5 km height intervals from 70 to 130 km at different sites.

POLYTDD (Specifies polynomial for obtaining temperature differences Datafile) is a file of input parameters for TDIFAVP4: IH1, IH2 = the range of data in THADATA to be utilized, NOBS = the number of single profiles to which a monthly mean is equated for purposes of weighting (finally taken as 3); ISLT = 0 or 1 according to whether local solar time is excluded or included in MSIS-86, ILONG1 = ILONG2 = 0 or 1 according to whether longitude dependences are excluded or included in lower model or upper model (i.e. MSIS-86), NCOND = number of coefficients (= 7) of the interpolating polynomial between heights z_1 and z_2, NF107 (= 120) and NP (= 10) are values of solar activity parameters $F_{10.7}$ and A_p which are adopted when no other values are specified, NRUN = reference number assigned to a particular computer run, IMSIS = 0 for normal use of TDIFAVP4 and = 99 to give tables of T - TMSIS where T is a polynomial model temperature and TMSIS is the corresponding MSIS-86 value, ISAX (= 7) and INAX (= 2) are the values of S and N in Appendix B, NOSCZ1 = 0 for RNDEL to be set zero in BCZ12 so that no sunspot number dependence is introduced into the lower model.

DUMMYAXD (Dummy set of a_{sn} coefficients Datafile) is datafile of a_{sn} all of which are zero.

TEMPS (Temperature etc Subprogram) is

```
SUBROUTINE TEMP(ZHT1,ZHT2,ZHTD,IHEND,Z1,Z2,IDAY,MN,GLAT,GLONG,
     SLT,F107A,F107,AP,TT,DN,PR,TOTND,RCL,ZZTURB,DDFZ2,DMXZ2)
```

which calculates at each of IHEND heights from ZHT1 to ZHT2 at a height interval of ZHTD the temperature TT, the number densities of individual gas constituents DN(I), $I \neq 6$ and the total mass density DN(6), the total no. density TOTND, the parameter RCL(I) ($= R'_{lI}$ from equation A5.16), the 'turbopause' heights ZZTURB(I) ($= z_{hI}$ of equation A.97), diffusion profile number densities DDFZ2(I) ($= n_d(z_2,M_I)$) and mixing profile number densities DMXZ2(I) ($= n_m(z_2,M_I)$) at height z_2 of the gas constituents.

LINES (Line Subprogram) is

SUBROUTINE LINE(CHAR)

which reads in and writes out a line of characters.

CF1880S (Coefficients for 18 - 80 km model Subprogram) is

SUBROUTINE CF1880(CC,DELG,WAV)

which reads in TPW12Q and derives DELG and WAV for use in BCATZZS and then reads in COEFFDQ into CC.

CFZ1Z2S (Coefficients a_{sn} for z_1 to z_2 model Subprogram) is

SUBROUTINE CFZ1Z2

which reads in and writes out a_{sn}.

PARAMD (Parameter Datafile) runs TVALP with ZHT1, ZHT2, ZHTD; MN1, MN2, MND; LAT1, LAT2, LATD; LNG1, LNG2, LNGD; ISLT1, ISLT2, ISLTD as the ranges of height, month, latitude, longitude and local solar time and their respective increments at which values are required to be evaluated; IXLONG = 0 gives zonal mean values; ICHPAR, ITPDN, ICHNUM, IATMOS, ITMOSN = 0, 1 for output subroutines CHPARM, TPDN, CHNUM, ATMOS and ATMOSN not to be called or to be called; IXSLT = 0 gives diurnal mean values in MSIS-86; solar activity parameters for which TVALP

is to run are listed as F107A, F107, AP(1),..AP(7), SW(9), and NOSCZ1, where SW(9) controls the use of AP(I) in GTS5 (i.e. MSIS-86) and NOSCZ1 = 0, 1 excludes or includes solar cycle dependence in the lower model according to SCATZ1.

PRM86D1 (Parameters for MSIS-86 Datafile with TVAL1KMP) gives ZHT1 (= 65.), ZHT2 (= 135.), ZHTD (= 1.); LAT1 (= -80); LAT2 (= 80); LATD (= 10); LNG1, LNG2, LNGD; ISLT1, ISLT2, ISLTD as the ranges of height, latitude, longitude and local solar time and their respective increments at which values are required to be evaluated; IXLONG = 0 gives zonal mean values; IXSLT = 0 gives diurnal mean values in MSIS-86, ICHPAR (= 0), IATMOS (= 0); ITMOSN (= 0), ITPDTB (= 1) for output subroutines CHPARM, ATMOS, ATMOSN, TPDTB1 not to be called or to be called; IMSIS = 0 for normal use, otherwise tables of values of MSIS-86 are generated; tables are generated for given dates specified by day of month and month as IDAT(I), MON(I), I = 1,..NDAYS; IDAT(I) = 0 gives mid-month values; IXMN = 0 gives annual mean, = 1 for given dates as specified above; solar activity parameters for which TVAL1KMP is run and their controlling parameters SW(9) and NOSCZ1 are supplied as in PARAMD.

PRM86D5 (Parameters for MSIS-86 Datafile with TVAL5KMP) is the same as PRM86D1 with different height and latitude ranges; ZHT1 (= 70.), ZHT2 (= 130.), ZHTD (= 5.); LAT1 (= -80), LAT2 (= 80), LATD (= 20).

APPENDIX F EXAMPLES OF TABULATIONS OF TEMPERATURES, PRESSURES AND DENSITIES

Two formats have been devised for tabulating diurnal and zonal means of mid-month values of temperature, pressure and density:

(i) With a 1 km height interval and a 10° increment of latitude such that each of the three parameters requires 1 page per month. The height range is 65 - 135 km, the values for 65 - 70 km being those of the lower model and those for 130 - 135 km being from the upper model.

(ii) With a 5 km height interval and a 20° increment of latitude such that all three parameters for 4 consecutive months fit on one page for the height range 70 - 130 km. The months on each page are grouped as January - April, May - August, September - December.

The examples presented are all for solar activity parameters $F_{10.7} = 150$, $A_p = 4$ and for Case 2 of Section 4.2.

JANUARY TEMPERATURE (K)

DIURNAL AND ZONAL MEAN OF MID-MONTH VALUES

AP = 4.0 F107 =150.0

LAT= KM	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80 DEG
65	251.1	247.9	242.0	235.6	231.3	230.8	233.3	236.3	237.7	236.7	233.5	229.5	226.7	226.6	229.7	234.9	239.6
66	246.6	243.4	237.8	231.5	227.5	227.2	229.7	232.6	234.0	233.1	230.5	227.4	225.2	225.4	228.4	232.9	237.0
67	241.9	238.9	233.4	227.4	223.7	223.6	226.1	228.9	230.1	229.5	227.6	225.3	223.9	224.4	227.1	231.1	234.4
68	236.9	234.1	228.9	223.3	220.0	220.1	222.6	225.2	226.3	225.9	224.6	223.3	222.6	223.5	226.0	229.3	232.0
69	231.8	229.1	224.4	219.2	216.4	216.8	219.2	221.5	222.4	222.2	221.7	221.3	221.4	222.7	225.0	227.7	229.8
70	226.5	224.0	219.7	215.2	212.9	213.6	216.0	217.9	218.6	218.6	218.8	219.2	220.2	221.9	224.2	226.3	227.8
71	221.0	218.8	215.0	211.1	209.5	210.6	212.9	214.5	214.8	215.1	215.9	217.2	218.9	221.1	223.3	225.1	226.0
72	215.5	213.5	210.1	207.0	206.2	207.9	210.2	211.3	211.4	211.7	213.1	215.3	217.7	220.2	222.6	224.1	224.5
73	210.1	208.1	205.2	203.0	203.1	205.4	207.8	208.6	208.3	208.7	210.6	213.4	216.5	219.4	221.8	223.1	223.2
74	204.8	202.9	200.3	198.9	200.1	203.2	205.8	206.3	205.6	206.0	208.3	211.8	215.4	218.6	221.0	222.1	222.0
75	199.7	197.7	195.5	195.0	197.3	201.4	204.2	204.3	203.3	203.6	206.3	210.3	214.3	217.8	220.3	221.1	220.8
76	194.8	192.7	190.8	191.2	194.7	199.7	203.0	202.8	201.3	201.6	204.5	208.9	213.4	217.1	219.5	220.2	219.5
77	190.1	187.9	186.4	187.6	192.3	198.4	202.0	201.5	199.7	199.8	202.9	207.7	212.6	216.4	218.7	219.1	218.3
78	185.6	183.4	182.3	184.4	190.2	197.2	201.2	200.5	198.3	198.2	201.4	206.7	211.9	215.8	218.0	218.1	216.9
79	181.3	179.2	178.5	181.4	188.3	196.2	200.6	199.7	197.0	196.8	200.1	205.7	211.2	215.3	217.3	217.0	215.5
80	177.2	175.3	175.1	178.8	186.6	195.4	200.0	199.0	196.0	195.5	198.9	204.8	210.7	214.9	216.5	215.8	213.9
81	173.4	171.8	172.1	176.6	185.2	194.6	199.5	199.3	195.0	194.3	197.8	204.0	210.2	214.5	215.8	214.5	212.2
82	169.8	168.6	169.5	174.7	184.1	194.0	199.0	197.6	194.0	193.1	196.7	203.1	209.7	214.1	215.2	213.2	210.3
83	166.5	165.8	167.4	173.3	183.2	193.4	198.4	196.9	193.1	192.0	195.6	202.3	209.2	213.8	214.5	211.9	208.4
84	163.5	163.4	165.7	172.3	182.6	192.9	197.8	196.0	192.1	190.9	194.5	201.4	208.7	213.4	213.8	210.5	206.4
85	160.8	161.4	164.5	171.7	182.3	192.4	197.0	195.1	191.1	189.8	193.4	200.5	208.2	213.1	213.1	209.1	204.4
86	158.5	159.7	163.7	171.5	182.1	191.9	196.1	194.1	190.0	188.8	192.2	199.5	207.6	212.7	212.4	207.7	202.4
87	156.5	158.5	163.3	171.6	182.2	191.5	195.1	193.0	189.0	187.7	191.1	198.5	206.9	212.2	211.6	206.3	200.4
88	154.8	157.7	163.4	172.2	182.6	191.0	194.1	191.8	187.9	186.6	190.0	197.5	206.2	211.7	210.8	204.9	198.5
89	153.6	157.2	163.8	173.1	183.1	190.6	192.9	190.5	186.8	185.6	188.9	196.4	205.4	211.0	210.0	203.5	196.7
90	152.7	157.2	164.7	174.3	183.8	190.2	191.7	189.2	185.8	184.6	187.8	195.3	204.4	210.3	209.1	202.2	195.0
91	152.4	157.7	166.0	175.9	184.7	189.9	190.5	188.0	184.8	183.8	186.8	194.2	203.4	209.4	208.1	201.0	193.5
92	152.4	158.6	167.7	177.8	185.7	189.6	189.4	186.8	183.9	183.0	185.9	193.2	202.4	208.4	207.1	199.9	192.3
93	153.0	159.9	169.8	179.9	186.9	189.4	188.3	185.7	183.2	182.4	185.2	192.2	201.3	207.3	206.1	198.8	191.3
94	154.1	161.7	172.3	182.4	188.3	189.3	187.4	184.8	182.7	182.0	184.6	191.3	200.2	206.2	205.0	198.0	190.6
95	155.7	163.9	175.1	185.0	189.8	189.3	186.7	184.1	182.4	181.9	184.2	190.5	199.1	205.0	204.0	197.2	190.2
96	157.9	166.7	178.4	188.0	191.4	189.6	186.2	183.7	182.3	182.0	184.1	189.9	198.0	203.7	202.9	196.7	190.1
97	160.8	170.0	181.9	191.1	193.2	190.0	185.9	183.6	182.6	182.4	184.2	189.5	197.0	202.5	202.0	196.4	190.4
98	164.3	173.8	185.9	194.4	195.2	190.6	186.0	183.8	183.2	183.2	184.7	189.3	196.2	201.3	201.1	196.3	191.1
99	168.5	178.2	190.1	197.8	197.3	191.6	186.5	184.5	184.2	184.3	185.5	189.4	195.5	200.3	200.3	196.5	192.2
100	173.4	183.1	194.8	201.5	199.6	192.8	187.4	185.5	185.7	185.9	186.7	189.9	195.1	199.3	199.8	196.9	193.7
101	179.2	188.7	199.7	205.3	202.0	194.4	188.7	187.1	187.6	187.9	188.3	190.6	194.9	198.6	199.4	197.7	195.7
102	185.9	195.0	205.0	209.2	204.7	196.3	190.4	189.1	190.0	190.3	190.3	191.8	195.0	198.1	199.3	198.8	198.1
103	193.7	201.9	210.7	213.4	207.6	198.6	192.7	191.7	192.9	193.3	192.8	193.3	195.5	198.0	199.5	200.4	201.2
104	202.4	209.6	216.7	217.7	210.8	201.4	195.6	194.8	196.4	196.8	195.8	195.3	196.3	198.2	200.1	202.4	204.8
105	212.4	218.0	223.0	222.2	214.3	204.7	199.0	198.6	200.5	200.9	199.3	197.8	197.7	198.8	201.2	204.9	209.0
106	223.5	227.1	229.7	226.9	218.2	208.5	203.1	203.1	205.2	205.6	203.5	200.8	199.5	199.9	202.7	207.9	213.9
107	235.9	237.0	236.7	231.9	222.5	212.9	207.9	208.2	210.7	211.0	208.2	204.5	201.9	201.6	204.7	211.5	219.4
108	249.5	247.7	244.2	237.3	227.3	217.9	213.4	214.2	216.9	217.1	213.7	208.8	204.9	203.9	207.4	215.7	225.6
109	264.5	259.1	252.0	243.0	232.6	223.7	219.8	221.0	224.0	224.1	220.0	213.8	208.6	206.9	210.7	220.6	232.6
110	280.6	271.2	260.2	249.2	238.5	230.3	227.0	228.7	231.9	231.8	227.0	219.7	213.2	210.7	214.8	226.2	240.2
111	297.8	283.9	268.9	255.9	245.1	237.7	235.2	237.4	240.7	240.5	234.9	226.3	218.5	215.3	219.8	232.6	248.7
112	316.0	297.2	278.1	263.2	252.5	246.0	244.4	247.1	250.5	250.0	243.8	233.9	224.3	220.9	225.6	239.9	258.0
113	334.7	310.9	287.9	271.3	260.8	255.2	254.6	257.8	261.3	260.5	253.5	242.5	232.1	227.5	232.5	248.1	268.1
114	353.7	325.0	298.2	280.1	270.0	265.5	265.9	269.5	273.1	272.0	264.3	252.2	240.6	235.2	240.5	257.3	279.0
115	372.5	339.3	309.1	289.7	280.2	277.0	278.3	282.4	285.9	284.5	276.1	262.9	250.3	244.3	249.7	267.5	290.8
116	390.6	353.6	320.9	300.7	291.6	289.5	291.9	296.3	299.7	298.0	289.0	274.9	261.3	254.7	260.2	278.9	303.3
117	407.6	367.9	333.1	312.5	304.1	303.3	306.5	311.3	314.5	312.4	302.9	288.1	273.7	266.6	272.2	291.4	316.5
118	423.0	382.0	346.3	325.6	317.9	318.2	322.3	327.2	330.1	327.7	317.8	302.5	287.6	280.1	285.7	305.1	330.4
119	436.6	395.8	360.1	339.8	333.0	334.3	339.0	344.0	346.6	343.7	333.7	318.1	302.9	295.3	300.7	319.9	344.8
120	448.4	409.3	374.8	355.3	349.3	351.4	356.6	361.5	363.6	360.3	350.3	334.9	319.8	312.1	317.2	335.8	359.6
121	458.3	422.4	390.1	371.9	366.7	369.4	374.8	379.4	381.0	377.4	367.5	352.6	337.9	330.4	335.2	352.7	374.7
122	466.8	435.2	406.1	389.6	385.1	388.1	393.4	397.6	398.5	394.7	385.1	371.0	357.1	350.0	354.3	370.2	389.9
123	474.4	447.7	422.6	408.0	404.3	407.2	412.1	415.7	416.0	411.9	402.8	389.7	377.1	370.6	374.3	388.2	405.0
124	481.6	460.2	439.4	427.0	423.7	426.3	430.6	433.5	433.2	428.9	420.2	408.5	397.3	391.6	394.7	406.1	419.8
125	489.1	472.7	456.3	446.0	443.1	445.1	448.6	450.7	449.9	445.4	437.2	426.7	417.1	412.2	414.7	423.7	434.2
126	497.6	485.6	472.9	464.5	461.7	463.1	465.7	467.1	465.8	461.1	453.3	444.0	435.8	431.8	433.7	440.4	448.0
127	507.5	499.8	489.1	482.1	479.3	479.9	481.8	482.8	481.0	476.1	468.5	459.8	452.8	449.5	450.9	455.9	461.2
128	519.3	512.6	504.6	498.4	495.4	495.4	496.9	497.5	495.5	490.2	482.5	474.1	467.6	464.8	465.9	469.8	473.7
129	533.0	526.9	519.4	513.1	509.9	509.6	510.9	511.4	509.2	503.6	495.5	486.9	480.4	477.6	478.7	482.2	485.7
130	547.8	541.4	533.4	526.7	523.2	522.9	524.2	524.7	522.4	516.4	507.7	498.5	491.6	488.7	489.9	493.6	497.2
131	562.6	555.7	547.1	539.8	536.0	535.7	537.1	537.7	535.2	528.8	519.5	509.7	502.3	499.2	500.5	504.4	509.3
132	577.1	569.7	560.5	552.7	548.6	548.2	549.7	550.3	547.7	540.9	531.0	520.6	512.7	509.4	510.9	515.1	519.2
133	591.3	583.4	573.5	565.3	560.8	560.4	562.0	562.6	559.8	552.7	542.3	531.3	522.9	519.5	521.0	525.4	529.7
134	605.1	596.8	586.4	577.6	572.8	572.3	574.0	574.6	571.6	564.1	553.2	541.7	532.9	529.3	530.8	535.4	540.0
135	618.7	609.9	598.9	589.6	584.6	584.0	585.6	586.2	583.1	575.3	563.9	551.8	542.6	538.8	540.4	545.2	549.9

JANUARY PRESSURE (N/M SQ)

DIURNAL AND ZONAL MEAN OF MID-MONTH VALUES

AP = 4.0 F107 =150.0

LAT= KM	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80 DEG	
65	1.757	1.705	1.596	1.453	1.325	1.238	1.190	1.174	1.177	1.175	1.137	1.056	0.959	0.876	0.811	0.756	0.713	+ 1
66	1.535	1.438	1.308	1.259	1.145	1.059	1.030	1.019	1.022	1.019	0.984	0.912	0.827	0.756	0.701	0.655	0.619	
67	1.339	1.294	1.204	1.088	0.987	0.927	0.890	0.831	0.885	0.832	0.851	0.787	0.713	0.651	0.605	0.567	0.537	
68	1.163	1.123	1.042	0.938	0.849	0.773	0.767	0.761	0.765	0.762	0.734	0.678	0.614	0.561	0.522	0.490	0.465	
69	1.008	0.972	0.898	0.807	0.729	0.631	0.659	0.655	0.659	0.657	0.632	0.583	0.528	0.483	0.450	0.423	0.402	
70	8.712	8.385	7.727	6.915	6.236	5.829	5.657	5.631	5.665	5.644	5.432	5.014	4.538	4.153	3.876	3.652	3.474	+ 0
71	7.503	7.211	6.627	5.913	5.326	4.933	4.845	4.828	4.860	4.842	4.661	4.305	3.900	3.573	3.339	3.150	2.998	
72	6.436	6.176	5.662	5.040	4.536	4.248	4.138	4.129	4.156	4.142	3.990	3.689	3.347	3.071	2.874	2.734	2.584	
73	5.499	5.270	4.820	4.282	3.853	3.615	3.528	3.523	3.546	3.535	3.409	3.158	2.870	2.638	2.473	2.336	2.225	
74	4.679	4.478	4.087	3.626	3.265	3.071	3.003	3.000	3.019	3.010	2.908	2.699	2.459	2.265	2.126	2.010	1.915	
75	3.966	3.789	3.452	3.060	2.760	2.634	2.552	2.551	2.565	2.558	2.476	2.305	2.105	1.943	1.827	1.729	1.646	
76	3.347	3.192	2.903	2.574	2.328	2.235	2.167	2.166	2.176	2.171	2.105	1.966	1.801	1.667	1.570	1.486	1.414	
77	2.813	2.678	2.432	2.158	1.960	1.865	1.838	1.837	1.843	1.839	1.788	1.675	1.540	1.429	1.348	1.276	1.214	
78	2.354	2.237	2.029	1.804	1.646	1.576	1.559	1.557	1.559	1.556	1.516	1.426	1.316	1.224	1.157	1.095	1.041	
79	1.967	1.860	1.686	1.503	1.380	1.330	1.320	1.318	1.318	1.314	1.285	1.214	1.124	1.049	0.992	0.939	0.892	
80	1.628	1.541	1.396	1.249	1.155	1.122	1.118	1.116	1.112	1.109	1.087	1.032	0.960	0.898	0.851	0.805	0.763	
81	1.345	1.279	1.151	1.035	0.966	0.946	0.947	0.944	0.938	0.935	0.919	0.877	0.819	0.769	0.729	0.689	0.652	
82	1.107	1.044	0.947	0.856	0.806	0.797	0.831	0.798	0.791	0.788	0.777	0.745	0.699	0.658	0.624	0.590	0.557	
83	9.079	8.552	7.768	7.066	6.724	6.713	6.727	6.740	6.661	6.628	6.556	6.318	5.963	5.632	5.346	5.038	4.749	- 1
84	7.415	6.982	6.358	5.826	5.605	5.630	5.729	5.671	5.606	5.572	5.528	5.359	5.085	4.819	4.575	4.332	4.043	
85	6.035	5.635	5.175	4.800	4.670	4.734	4.841	4.802	4.713	4.630	4.658	4.541	4.335	4.122	3.913	3.670	3.437	
86	4.896	4.618	4.239	3.952	3.890	3.978	4.038	4.048	3.960	3.927	3.921	3.846	3.694	3.526	3.346	3.129	2.918	
87	3.961	3.745	3.458	3.255	3.241	3.362	3.430	3.410	3.324	3.292	3.297	3.255	3.147	3.015	2.860	2.663	2.473	
88	3.197	3.033	2.820	2.682	2.701	2.826	2.939	2.870	2.787	2.738	2.771	2.753	2.680	2.578	2.444	2.265	2.093	
89	2.576	2.454	2.301	2.212	2.252	2.375	2.451	2.413	2.336	2.308	2.326	2.326	2.281	2.203	2.087	1.925	1.769	
90	2.073	1.986	1.879	1.827	1.880	1.976	2.063	2.027	1.956	1.931	1.951	1.965	1.941	1.883	1.782	1.635	1.493	
91	1.667	1.608	1.537	1.512	1.570	1.677	1.736	1.702	1.636	1.614	1.636	1.659	1.651	1.609	1.521	1.388	1.260	
92	1.340	1.304	1.260	1.254	1.314	1.409	1.459	1.427	1.368	1.348	1.371	1.399	1.404	1.374	1.298	1.177	1.061	
93	1.079	1.059	1.036	1.042	1.100	1.184	1.225	1.176	1.144	1.126	1.148	1.180	1.193	1.173	1.107	0.998	0.894	
94	0.869	0.862	0.854	0.868	0.923	0.995	1.028	1.001	0.956	0.941	0.962	0.994	1.013	1.001	0.943	0.846	0.753	
95	7.020	7.033	7.060	7.259	7.756	8.363	8.629	8.332	7.988	7.836	8.052	8.376	8.599	8.539	8.040	7.166	6.336	- 2
96	5.686	5.761	5.859	6.085	6.529	7.033	7.238	7.015	6.676	6.564	6.743	7.055	7.296	7.279	6.849	6.072	5.336	
97	4.623	4.737	4.861	5.118	5.506	5.918	6.071	5.871	5.582	5.438	5.650	5.942	6.188	6.202	5.832	5.145	4.496	
98	3.775	3.912	4.063	4.317	4.652	4.934	5.093	4.916	4.670	4.573	4.736	5.005	5.246	5.261	4.965	4.360	3.792	
99	3.098	3.246	3.430	3.654	3.938	4.231	4.274	4.118	3.912	3.848	3.974	4.217	4.446	4.495	4.225	3.697	3.202	
100	2.557	2.708	2.894	3.103	3.341	3.546	3.591	3.434	3.282	3.229	3.339	3.556	3.767	3.823	3.595	3.137	2.708	
101	2.124	2.271	2.452	2.643	2.841	2.977	3.020	2.931	2.759	2.716	2.810	3.000	3.193	3.251	3.059	2.665	2.295	
102	1.776	1.916	2.058	2.259	2.421	2.538	2.545	2.442	2.324	2.239	2.370	2.535	2.707	2.764	2.603	2.266	1.950	
103	1.496	1.626	1.746	1.938	2.069	2.153	2.149	2.061	1.964	1.935	2.004	2.145	2.296	2.351	2.216	1.930	1.662	
104	1.270	1.389	1.534	1.667	1.772	1.832	1.819	1.744	1.664	1.642	1.699	1.819	1.950	2.000	1.888	1.647	1.420	
105	1.086	1.193	1.324	1.439	1.523	1.562	1.545	1.481	1.416	1.397	1.445	1.546	1.658	1.703	1.611	1.409	1.218	
106	0.936	1.032	1.148	1.247	1.312	1.337	1.317	1.262	1.209	1.194	1.233	1.318	1.412	1.451	1.376	1.209	1.049	
107	0.814	0.898	1.000	1.083	1.134	1.148	1.126	1.080	1.037	1.025	1.057	1.127	1.206	1.239	1.178	1.039	0.907	
108	0.713	0.787	0.875	0.945	0.983	0.939	0.968	0.929	0.894	0.834	0.910	0.967	1.032	1.060	1.010	0.897	0.788	
109	6.291	6.931	7.687	8.269	8.553	8.562	8.395	8.030	7.746	7.686	7.871	8.331	8.863	9.094	8.691	7.765	6.872	- 3
110	5.594	6.143	6.784	7.262	7.470	7.443	7.249	6.976	6.746	6.679	6.842	7.211	7.633	7.825	7.530	6.731	6.024	
111	5.009	5.475	6.014	6.402	6.551	6.530	6.323	6.095	5.908	5.851	5.977	6.270	6.610	6.757	6.497	5.895	5.307	
112	4.515	4.907	5.353	5.665	5.768	5.735	5.546	5.355	5.203	5.154	5.250	5.479	5.745	5.859	5.651	5.170	4.699	
113	4.095	4.420	4.786	5.032	5.101	5.032	4.891	4.732	4.608	4.566	4.657	4.814	5.019	5.104	4.937	4.597	4.181	
114	3.735	4.001	4.296	4.488	4.531	4.462	4.339	4.207	4.104	4.067	4.118	4.252	4.407	4.469	4.336	4.056	3.759	
115	3.423	3.638	3.873	4.020	4.044	3.978	3.871	3.761	3.676	3.643	3.678	3.777	3.892	3.934	3.827	3.593	3.360	
116	3.151	3.322	3.505	3.616	3.627	3.566	3.474	3.382	3.311	3.281	3.303	3.374	3.456	3.483	3.397	3.215	3.035	
117	2.912	3.045	3.185	3.266	3.268	3.213	3.135	3.058	2.998	2.970	2.982	3.031	3.087	3.102	3.032	2.892	2.754	
118	2.700	2.801	2.905	2.963	2.959	2.910	2.844	2.779	2.729	2.703	2.707	2.738	2.774	2.779	2.723	2.615	2.510	
119	2.510	2.585	2.661	2.701	2.692	2.650	2.594	2.539	2.496	2.471	2.470	2.487	2.508	2.505	2.459	2.377	2.298	
120	2.339	2.392	2.446	2.472	2.461	2.425	2.377	2.331	2.294	2.270	2.264	2.271	2.280	2.272	2.234	2.171	2.112	
121	2.184	2.220	2.256	2.272	2.260	2.229	2.189	2.149	2.117	2.094	2.085	2.084	2.085	2.073	2.040	1.992	1.949	
122	2.042	2.066	2.088	2.097	2.085	2.058	2.024	1.990	1.961	1.940	1.928	1.922	1.916	1.902	1.874	1.837	1.804	
123	1.912	1.926	1.940	1.943	1.931	1.909	1.880	1.850	1.823	1.803	1.789	1.780	1.770	1.754	1.730	1.700	1.674	
124	1.792	1.800	1.807	1.806	1.796	1.776	1.751	1.725	1.701	1.682	1.667	1.655	1.643	1.626	1.604	1.580	1.562	
125	1.682	1.686	1.688	1.686	1.676	1.659	1.637	1.613	1.591	1.573	1.558	1.545	1.530	1.513	1.493	1.474	1.459	
126	1.581	1.582	1.582	1.578	1.569	1.554	1.535	1.513	1.493	1.475	1.460	1.446	1.431	1.414	1.396	1.379	1.367	
127	1.487	1.487	1.485	1.481	1.473	1.459	1.442	1.423	1.404	1.387	1.371	1.357	1.342	1.325	1.308	1.293	1.283	
128	1.401	1.400	1.398	1.393	1.386	1.374	1.358	1.340	1.323	1.306	1.291	1.277	1.262	1.245	1.229	1.216	1.206	
129	1.322	1.321	1.318	1.314	1.306	1.276	1.282	1.265	1.248	1.233	1.218	1.204	1.189	1.173	1.158	1.145	1.137	
130	1.250	1.248	1.245	1.241	1.234	1.224	1.211	1.196	1.180	1.165	1.151	1.136	1.122	1.106	1.092	1.080	1.073	
131	1.184	1.181	1.178	1.174	1.167	1.159	1.147	1.133	1.118	1.103	1.089	1.075	1.060	1.045	1.032	1.021	1.014	
132	1.122	1.120	1.116	1.112	1.106	1.078	1.087	1.074	1.060	1.046	1.032	1.018	1.003	0.989	0.976	0.966	0.959	
133	1.066	1.063	1.059	1.055	1.049	1.042	1.032	1.020	1.007	0.993	0.979	0.965	0.951	0.937	0.925	0.915	0.909	
134	1.014	1.010	1.006	1.002	0.997	0.970	0.931	0.970	0.957	0.944	0.930	0.916	0.902	0.889	0.877	0.868	0.863	
135	9.649	9.615	9.571	9.525	9.474	9.416	9.336	9.233	9.113	8.982	8.846	8.705	8.566	8.437	8.328	8.246	8.196	- 4

(1 N/M SQ = 0.01 MB)

JANUARY DENSITY (KG/M CU)

DIURNAL AND ZONAL MEAN OF MID-MONTH VALUES

AP = 4.0 F107 =150.0

LAT= KM	-80	-70	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80 DEG	
65	2.437	2.397	2.297	2.150	1.996	1.808	1.778	1.731	1.725	1.729	1.696	1.602	1.474	1.347	1.231	1.121	1.036	- 4
66	2.169	2.129	2.033	1.895	1.754	1.640	1.563	1.525	1.521	1.523	1.487	1.397	1.280	1.168	1.069	0.980	0.910	
67	1.928	1.888	1.797	1.667	1.538	1.437	1.371	1.341	1.340	1.339	1.302	1.217	1.109	1.011	0.928	0.855	0.798	
68	1.711	1.672	1.585	1.464	1.345	1.255	1.200	1.177	1.177	1.175	1.138	1.058	0.960	0.874	0.804	0.745	0.679	
69	1.515	1.479	1.395	1.282	1.173	1.074	1.048	1.031	1.032	1.029	0.993	0.919	0.831	0.755	0.697	0.647	0.610	
70	1.340	1.304	1.225	1.120	1.021	0.931	0.912	0.900	0.903	0.899	0.865	0.797	0.718	0.652	0.602	0.562	0.531	
71	1.182	1.148	1.074	0.975	0.885	0.824	0.772	0.734	0.788	0.734	0.752	0.690	0.629	0.563	0.521	0.487	0.462	
72	1.040	1.007	0.938	0.848	0.766	0.712	0.636	0.630	0.665	0.631	0.652	0.597	0.535	0.486	0.450	0.422	0.401	
73	9.114	8.816	8.179	7.345	6.605	6.128	5.912	5.831	5.928	5.897	5.637	5.151	4.616	4.166	3.832	3.647	3.472	- 5
74	7.955	7.686	7.105	6.346	5.681	5.250	5.030	5.065	5.113	5.038	4.860	4.438	3.975	3.607	3.349	3.152	3.034	
75	6.914	6.673	6.148	5.465	4.871	4.533	4.352	4.346	4.394	4.374	4.179	3.817	3.420	3.106	2.868	2.722	2.596	
76	5.982	5.768	5.297	4.688	4.163	3.844	3.718	3.719	3.763	3.750	3.585	3.276	2.938	2.673	2.490	2.350	2.243	
77	5.152	4.961	4.543	4.005	3.548	3.274	3.169	3.174	3.214	3.205	3.068	2.808	2.522	2.299	2.145	2.027	1.936	
78	4.416	4.246	3.875	3.406	3.014	2.733	2.697	2.733	2.738	2.733	2.621	2.403	2.163	1.975	1.847	1.748	1.671	
79	3.767	3.614	3.288	2.884	2.552	2.361	2.272	2.298	2.328	2.326	2.235	2.054	1.853	1.696	1.590	1.507	1.441	
80	3.198	3.059	2.775	2.431	2.155	2.030	1.946	1.932	1.976	1.976	1.903	1.754	1.586	1.455	1.368	1.299	1.242	
81	2.701	2.575	2.329	2.040	1.815	1.692	1.632	1.637	1.676	1.676	1.618	1.497	1.357	1.248	1.176	1.118	1.071	
82	2.270	2.156	1.945	1.705	1.524	1.430	1.401	1.405	1.419	1.420	1.375	1.276	1.161	1.070	1.010	0.962	0.922	
83	1.898	1.796	1.615	1.417	1.277	1.218	1.139	1.172	1.201	1.201	1.167	1.087	0.992	0.917	0.858	0.828	0.793	
84	1.578	1.487	1.335	1.177	1.068	1.019	1.038	1.010	1.016	1.016	0.969	0.926	0.848	0.766	0.745	0.711	0.682	
85	1.306	1.226	1.099	0.973	0.892	0.860	0.935	0.856	0.858	0.858	0.838	0.788	0.725	0.673	0.639	0.611	0.585	
86	1.075	1.006	0.901	0.802	0.743	0.725	0.725	0.726	0.725	0.724	0.710	0.671	0.619	0.577	0.548	0.524	0.502	
87	8.810	8.220	7.306	6.593	6.186	6.138	6.130	6.147	6.118	6.102	6.002	5.763	5.299	4.942	4.732	4.491	4.293	- 6
88	7.184	6.690	6.003	5.413	5.145	5.144	5.213	5.205	5.158	5.139	5.072	4.847	4.520	4.235	4.032	3.846	3.608	
89	5.832	5.427	4.882	4.444	4.276	4.331	4.416	4.403	4.346	4.323	4.281	4.117	3.861	3.629	3.456	3.269	3.127	
90	4.716	4.390	3.964	3.642	3.553	3.645	3.739	3.722	3.657	3.633	3.610	3.495	3.298	3.111	2.962	2.810	2.661	
91	3.800	3.542	3.215	2.985	2.952	3.066	3.162	3.142	3.074	3.048	3.040	2.964	2.817	2.667	2.537	2.397	2.259	
92	3.051	2.853	2.607	2.447	2.453	2.577	2.672	2.649	2.580	2.555	2.557	2.512	2.405	2.286	2.173	2.043	1.914	
93	2.444	2.296	2.114	2.007	2.039	2.166	2.254	2.230	2.163	2.138	2.148	2.126	2.052	1.960	1.860	1.739	1.619	
94	1.954	1.846	1.716	1.648	1.696	1.819	1.899	1.875	1.810	1.787	1.802	1.798	1.750	1.679	1.592	1.478	1.366	
95	1.559	1.484	1.394	1.356	1.412	1.526	1.597	1.573	1.513	1.492	1.509	1.518	1.492	1.439	1.361	1.255	1.151	
96	1.244	1.193	1.134	1.117	1.177	1.280	1.341	1.317	1.263	1.244	1.263	1.281	1.270	1.232	1.163	1.064	0.968	
97	0.992	0.961	0.925	0.923	0.981	1.073	1.124	1.101	1.052	1.035	1.055	1.079	1.080	1.053	0.993	0.901	0.812	
98	7.910	7.744	7.555	7.636	8.191	8.933	9.405	9.135	8.754	8.607	8.801	9.072	9.175	9.002	8.474	7.625	6.811	- 7
99	6.317	6.255	6.191	6.335	6.845	7.518	7.935	7.650	7.274	7.149	7.334	7.620	7.782	7.683	7.220	6.444	5.704	
100	5.053	5.064	5.087	5.269	5.727	6.239	6.531	6.362	6.038	5.932	6.105	6.392	6.591	6.548	6.144	5.460	4.774	
101	4.051	4.112	4.193	4.395	4.797	5.238	5.437	5.235	5.008	4.921	5.079	5.356	5.574	5.572	5.222	4.539	3.993	
102	3.256	3.349	3.468	3.675	4.024	4.376	4.542	4.307	4.153	4.081	4.224	4.484	4.708	4.734	4.432	3.867	3.339	
103	2.626	2.737	2.879	3.082	3.380	3.675	3.778	3.640	3.444	3.366	3.513	3.751	3.971	4.015	3.737	3.258	2.793	
104	2.126	2.245	2.398	2.592	2.842	3.073	3.142	3.020	2.858	2.811	2.922	3.137	3.345	3.401	3.131	2.743	2.336	
105	1.728	1.850	2.005	2.165	2.394	2.571	2.613	2.507	2.372	2.335	2.432	2.622	2.815	2.875	2.639	2.309	1.956	
106	1.411	1.530	1.662	1.847	2.019	2.132	2.174	2.082	1.972	1.942	2.026	2.192	2.366	2.428	2.271	1.944	1.640	
107	1.158	1.272	1.417	1.565	1.705	1.803	1.810	1.731	1.641	1.618	1.669	1.833	1.968	2.047	1.917	1.637	1.374	
108	0.956	1.063	1.198	1.330	1.442	1.512	1.509	1.441	1.368	1.350	1.411	1.534	1.669	1.724	1.616	1.379	1.157	
109	0.794	0.892	1.016	1.132	1.222	1.270	1.260	1.202	1.143	1.129	1.180	1.285	1.401	1.451	1.362	1.163	0.975	
110	0.663	0.753	0.865	0.966	1.036	1.068	1.053	1.005	0.957	0.947	0.989	1.077	1.177	1.221	1.148	0.981	0.824	
111	0.557	0.639	0.740	0.826	0.881	0.900	0.883	0.842	0.804	0.796	0.831	0.905	0.989	1.027	0.968	0.830	0.698	
112	4.720	5.450	6.345	7.080	7.499	7.630	7.423	7.078	6.770	6.710	7.003	7.613	8.311	8.636	8.160	7.023	5.931	- 8
113	4.028	4.677	5.461	6.080	6.397	6.433	6.237	5.968	5.722	5.677	5.917	6.419	6.995	7.268	6.836	5.937	5.056	
114	3.466	4.037	4.716	5.232	5.467	5.460	5.271	5.051	4.854	4.820	5.016	5.426	5.897	6.122	5.817	5.064	4.325	
115	3.007	3.505	4.046	4.511	4.682	4.647	4.491	4.291	4.135	4.109	4.268	4.599	4.980	5.163	4.920	4.315	3.713	
116	2.632	3.061	3.552	3.893	4.019	3.968	3.826	3.661	3.536	3.517	3.644	3.910	4.215	4.362	4.170	3.686	3.201	
117	2.325	2.688	3.097	3.375	3.459	3.399	3.273	3.137	3.039	3.024	3.125	3.335	3.576	3.692	3.541	3.158	2.770	
118	2.071	2.374	2.710	2.929	2.984	2.923	2.813	2.702	2.623	2.612	2.691	2.855	3.043	3.133	3.015	2.715	2.409	
119	1.861	2.109	2.378	2.549	2.583	2.524	2.429	2.338	2.276	2.267	2.328	2.455	2.599	2.666	2.574	2.343	2.104	
120	1.684	1.882	2.094	2.223	2.243	2.189	2.109	2.035	1.986	1.978	2.024	2.120	2.229	2.277	2.206	2.029	1.846	
121	1.534	1.688	1.850	1.945	1.955	1.907	1.840	1.781	1.742	1.735	1.769	1.839	1.918	1.953	1.898	1.766	1.628	
122	1.405	1.521	1.640	1.709	1.711	1.670	1.616	1.568	1.537	1.531	1.554	1.605	1.661	1.684	1.642	1.544	1.443	
123	1.292	1.375	1.460	1.507	1.505	1.471	1.427	1.389	1.364	1.358	1.374	1.409	1.447	1.460	1.428	1.358	1.286	
124	1.190	1.247	1.304	1.335	1.331	1.303	1.268	1.238	1.218	1.212	1.222	1.245	1.269	1.275	1.251	1.201	1.151	
125	1.097	1.134	1.171	1.189	1.184	1.162	1.134	1.110	1.093	1.088	1.094	1.108	1.122	1.123	1.104	1.070	1.036	
126	1.011	1.033	1.055	1.066	1.061	1.043	1.021	1.001	0.987	0.982	0.985	0.993	1.000	0.998	0.983	0.959	0.937	
127	9.308	9.432	9.558	9.613	9.564	9.426	9.246	9.078	8.961	8.910	8.922	8.965	8.990	8.949	8.827	8.659	8.513	- 9
128	8.553	8.625	8.698	8.727	8.684	8.570	8.420	8.275	8.172	8.125	8.128	8.151	8.153	8.103	7.999	7.871	7.767	
129	7.850	7.899	7.951	7.971	7.934	7.836	7.705	7.576	7.483	7.441	7.441	7.456	7.450	7.399	7.306	7.198	7.114	
130	7.206	7.250	7.297	7.317	7.284	7.197	7.079	6.962	6.877	6.839	6.839	6.853	6.846	6.798	6.711	6.613	6.537	
131	6.631	6.677	6.717	6.737	6.709	6.631	6.523	6.416	6.339	6.304	6.304	6.317	6.310	6.265	6.185	6.093	6.023	
132	6.119	6.158	6.200	6.220	6.195	6.125	6.027	5.930	5.859	5.826	5.826	5.837	5.831	5.788	5.713	5.629	5.563	
133	5.662	5.697	5.737	5.756	5.735	5.672	5.582	5.493	5.429	5.398	5.397	5.406	5.399	5.359	5.289	5.211	5.151	
134	5.251	5.284	5.321	5.339	5.321	5.264	5.182	5.101	5.041	5.013	5.011	5.018	5.010	4.973	4.908	4.835	4.780	
135	4.382	4.912	4.946	4.963	4.947	4.896	4.822	4.747	4.692	4.665	4.662	4.667	4.659	4.623	4.562	4.495	4.445	

AP = 4.0   F107 =150.0

DIURNAL AND ZONAL MEAN OF MID-MONTH VALUES

JANUARY — TEMPERATURE (K)

LAT= KM	-80	-60	-40	-20	0	20	40	60	80 DEG
70	226	220	213	216	219	219	220	224	220
75	200	195	197	204	203	206	211	220	221
80	177	175	187	200	196	199	211	217	214
85	161	164	182	197	191	193	203	213	204
90	153	165	184	192	186	188	204	209	195
95	156	175	190	187	182	184	197	204	190
100	173	195	200	187	186	187	193	209	194
105	212	223	214	199	200	199	193	201	207
110	281	260	238	227	232	227	213	215	240
115	372	309	280	278	286	276	253	250	291
120	448	375	349	357	364	350	323	317	360
125	489	456	443	449	450	437	417	415	434
130	548	533	523	524	522	508	492	490	497

JANUARY — PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	8.71	7.73	6.24	5.66	5.67	5.43	4.54	3.89	3.47	+ 0
75	3.97	3.45	2.76	2.55	2.57	2.48	2.10	1.83	1.65	
80	1.63	1.40	1.16	1.12	1.11	1.09	0.95	0.85	0.76	
85	5.04	5.19	4.67	4.84	4.71	4.66	4.34	3.91	3.44	- 1
90	2.07	1.88	1.88	2.06	1.96	1.95	1.94	1.78	1.49	
95	7.02	7.06	7.76	8.63	7.99	8.05	8.60	8.04	6.34	- 2
100	2.56	2.89	3.34	3.59	3.28	3.34	3.77	3.59	2.71	
105	1.09	1.32	1.52	1.54	1.42	1.44	1.60	1.61	1.22	
110	5.59	6.78	7.47	7.25	6.75	6.84	7.64	7.50	6.02	- 3
115	3.42	3.87	4.04	3.87	3.68	3.68	3.89	3.83	3.36	
120	2.34	2.45	2.46	2.38	2.29	2.26	2.23	2.23	2.11	
125	1.68	1.69	1.68	1.64	1.59	1.56	1.53	1.49	1.40	
130	1.25	1.25	1.23	1.21	1.18	1.15	1.12	1.09	1.07	

JANUARY — DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	1.34	1.23	1.02	0.91	0.90	0.87	0.72	0.60	0.53	- 4
75	6.91	6.15	4.87	4.35	4.39	4.18	3.42	2.89	2.60	- 5
80	3.20	2.78	2.16	1.95	1.98	1.90	1.57	1.37	1.24	
85	1.31	1.10	0.89	0.86	0.86	0.84	0.72	0.64	0.59	
90	4.72	3.96	3.55	3.74	3.60	3.61	3.30	2.96	2.60	- 6
95	1.56	1.39	1.41	1.60	1.51	1.51	1.47	1.36	1.15	
100	5.05	5.09	5.73	6.55	6.04	6.11	6.59	6.14	4.77	- 7
105	1.73	2.00	2.39	2.61	2.37	2.43	2.81	2.69	1.90	
110	0.66	0.87	1.04	1.05	0.96	0.99	1.13	1.15	0.82	
115	3.01	4.09	4.68	4.49	4.13	4.27	4.93	4.92	3.71	- 8
120	1.68	2.09	2.24	2.11	1.99	2.02	2.23	2.21	1.83	
125	1.10	1.17	1.18	1.13	1.09	1.09	1.12	1.10	1.04	
130	7.21	7.30	7.28	7.08	6.88	6.84	6.85	6.71	6.54	- 9

MARCH — TEMPERATURE (K)

KM	-80	-60	-40	-20	0	20	40	60	80
70	224	219	214	220	217	220	222	224	221
75	209	205	204	206	203	208	212	216	213
80	195	192	196	198	193	197	201	206	207
85	182	185	193	193	187	190	197	199	196
90	174	183	193	189	183	187	199	197	183
95	174	188	194	185	182	186	202	199	176
100	186	199	196	186	187	190	203	201	182
105	215	215	204	196	201	200	204	207	203
110	267	242	222	221	228	222	213	223	259
115	340	285	262	268	277	265	243	259	336
120	415	354	334	345	354	339	311	328	416
125	472	445	435	445	451	440	423	432	473
130	533	521	516	524	529	522	512	516	520

MARCH — PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	4.66	5.02	5.38	5.72	5.78	5.61	5.03	4.35	3.94	+ 0
75	2.15	2.28	2.42	2.61	2.61	2.57	2.33	2.04	1.83	
80	0.94	0.98	1.05	1.14	1.13	1.13	1.04	0.93	0.83	
85	3.86	4.04	4.45	4.88	4.70	4.77	4.43	4.06	3.64	- 1
90	1.51	1.63	1.88	2.05	1.92	1.98	1.93	1.75	1.51	
95	5.83	6.71	8.03	8.50	7.82	8.18	8.51	7.61	5.97	- 2
100	2.34	2.69	3.49	3.54	3.23	3.44	3.82	3.37	2.39	
105	1.04	1.32	1.56	1.52	1.41	1.51	1.73	1.53	1.04	
110	5.36	6.60	7.36	7.06	6.69	7.08	8.03	7.29	5.23	- 3
115	3.20	3.64	3.85	3.72	3.60	3.73	4.02	3.79	3.07	
120	2.14	2.29	2.30	2.26	2.23	2.25	2.30	2.24	2.06	
125	1.52	1.55	1.56	1.56	1.54	1.54	1.53	1.51	1.43	
130	1.14	1.15	1.16	1.16	1.15	1.14	1.13	1.11	1.10	

MARCH — DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	7.26	8.03	8.74	9.06	9.29	8.88	7.87	6.76	6.21	- 5
75	3.58	3.86	4.14	4.42	4.48	4.31	3.84	3.29	2.96	
80	1.67	1.77	1.86	2.01	2.03	1.99	1.83	1.56	1.30	
85	7.37	7.62	8.03	8.40	8.74	8.73	7.93	7.08	6.46	- 6
90	3.03	3.09	3.39	3.77	3.44	3.68	3.30	3.09	2.83	
95	1.16	1.23	1.43	1.58	1.48	1.52	1.43	1.33	1.10	
100	4.29	4.96	6.06	6.47	5.90	6.18	6.42	5.72	4.49	- 7
105	1.62	2.07	2.56	2.60	2.35	2.52	2.83	2.49	1.63	
110	0.66	0.90	1.09	1.05	0.96	1.05	1.24	1.08	0.67	
115	3.04	4.12	4.72	4.45	4.16	4.51	5.33	4.74	2.93	- 8
120	1.44	2.01	2.16	2.05	1.97	2.08	2.33	2.16	1.53	
125	1.01	1.08	1.10	1.07	1.05	1.07	1.11	1.09	0.93	
130	6.57	6.71	6.78	6.67	6.57	6.62	6.67	6.37	6.42	- 9

FEBRUARY — TEMPERATURE (K)

LAT= KM	-80	-60	-40	-20	0	20	40	60	80 DEG
70	223	217	213	218	217	218	221	227	232
75	199	196	201	206	203	207	213	221	222
80	179	177	193	204	195	197	207	215	214
85	166	168	190	203	190	190	204	209	201
90	160	170	191	196	185	186	203	203	187
95	164	182	193	187	182	185	201	200	178
100	180	201	197	183	185	189	199	193	182
105	216	225	206	191	199	201	201	201	202
110	275	256	226	216	229	225	213	217	243
115	354	299	266	260	281	271	247	254	309
120	428	364	335	348	359	344	316	323	336
125	491	451	439	447	451	433	420	423	451
130	542	529	521	525	526	514	501	501	510

FEBRUARY — PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	7.06	6.58	5.86	5.71	5.74	5.55	4.61	3.99	3.69	+ 0
75	3.19	2.92	2.61	2.59	2.60	2.53	2.14	1.89	1.86	
80	1.51	1.19	1.12	1.15	1.13	1.11	0.96	0.80	0.87	
85	4.98	4.50	4.69	5.08	4.75	4.70	4.28	4.03	3.68	- 1
90	1.78	1.67	1.96	2.22	1.96	1.95	1.89	1.79	1.64	
95	6.37	6.52	8.29	9.38	8.00	8.01	8.39	7.96	6.63	- 2
100	2.44	2.76	3.58	3.87	3.28	3.34	3.73	3.52	2.67	
105	1.06	1.29	1.60	1.62	1.41	1.40	1.57	1.57	1.15	
110	5.51	6.63	7.58	7.35	6.69	6.91	7.73	7.31	5.61	- 3
115	3.33	3.75	3.98	3.82	3.62	3.68	3.91	3.76	3.19	
120	2.24	2.35	2.38	2.31	2.25	2.24	2.27	2.21	2.06	
125	1.60	1.62	1.62	1.59	1.56	1.54	1.52	1.43	1.45	
130	1.19	1.19	1.19	1.18	1.16	1.14	1.11	1.09	1.07	

FEBRUARY — DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	1.10	1.06	0.96	0.91	0.92	0.89	0.73	0.61	0.58	- 4
75	5.59	5.21	4.54	4.38	4.44	4.26	3.49	2.99	2.92	- 5
80	2.55	2.34	2.02	1.96	2.00	1.96	1.63	1.43	1.41	
85	1.04	0.93	0.86	0.87	0.87	0.86	0.73	0.67	0.67	
90	3.88	3.42	3.56	3.92	3.69	3.64	3.24	3.03	3.06	- 6
95	1.35	1.24	1.48	1.73	1.52	1.50	1.44	1.37	1.28	
100	4.62	4.71	6.22	7.23	6.06	6.05	6.39	6.07	5.01	- 7
105	1.67	1.93	2.62	2.86	2.38	2.44	2.79	2.62	1.91	
110	0.66	0.86	1.11	1.12	0.96	1.01	1.19	1.11	0.76	
115	3.06	4.07	4.84	4.61	4.13	4.36	5.09	4.77	3.33	- 8
120	1.68	2.06	2.23	2.09	1.96	2.04	2.25	2.15	1.69	
125	1.05	1.13	1.14	1.10	1.07	1.03	1.11	1.03	1.00	
130	6.37	6.98	7.01	6.85	6.69	6.64	6.71	6.59	6.42	- 9

APRIL — TEMPERATURE (K)

KM	-80	-60	-40	-20	0	20	40	60	80
70	233	226	218	218	212	219	222	224	225
75	225	217	208	205	201	205	207	211	213
80	215	208	201	197	194	194	194	197	198
85	200	201	197	193	191	189	189	186	182
90	187	195	197	190	189	190	191	182	169
95	180	193	196	187	188	194	197	184	166
100	185	197	196	188	190	197	202	192	178
105	207	207	201	196	199	203	207	208	209
110	249	231	217	218	222	213	218	236	269
115	315	274	254	262	267	254	248	281	335
120	391	344	325	336	343	326	317	354	435
125	458	436	428	439	446	437	429	443	483
130	519	509	507	519	529	527	521	523	541

APRIL — PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	3.49	3.89	4.86	5.58	5.63	5.64	5.63	5.35	5.00	+ 0
75	1.68	1.83	2.22	2.53	2.51	2.57	2.59	2.43	2.33	
80	0.79	0.83	0.99	1.10	1.08	1.11	1.12	1.07	1.03	
85	3.32	3.69	4.23	4.71	4.55	4.65	4.68	4.56	4.29	- 1
90	1.49	1.59	1.82	1.98	1.90	1.94	1.95	1.84	1.65	
95	6.03	6.81	7.90	8.30	7.96	8.23	8.35	7.43	6.13	- 2
100	2.46	2.96	3.45	3.48	3.36	3.58	3.70	3.10	2.34	
105	1.08	1.33	1.54	1.50	1.47	1.60	1.68	1.33	1.01	
110	5.38	6.46	7.20	6.98	6.88	7.49	7.38	6.69	5.12	- 3
115	3.10	3.48	3.72	3.64	3.62	3.85	4.00	3.62	3.08	
120	2.02	2.13	2.20	2.19	2.20	2.26	2.31	2.22	2.09	
125	1.43	1.46	1.49	1.50	1.51	1.53	1.54	1.53	1.50	
130	1.06	1.08	1.10	1.12	1.13	1.14	1.14	1.13	1.12	

APRIL — DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	5.21	6.00	7.77	8.94	9.24	8.96	8.84	8.31	7.73	- 5
75	2.60	2.93	3.77	4.30	4.35	4.37	4.35	4.10	3.81	
80	1.27	1.39	1.70	1.95	1.93	2.00	2.02	1.94	1.82	
85	6.12	6.40	7.46	8.48	8.28	8.55	8.65	8.54	8.22	- 6
90	2.77	2.83	3.22	3.63	3.50	3.54	3.54	3.52	3.40	
95	1.16	1.22	1.39	1.53	1.46	1.47	1.46	1.40	1.28	
100	4.53	5.13	5.99	6.32	6.04	6.20	6.25	5.53	4.31	- 7
105	1.75	2.16	2.56	2.57	2.46	2.64	2.73	2.23	1.62	
110	0.71	0.92	1.09	1.05	1.02	1.13	1.20	0.94	0.63	
115	3.17	4.08	4.67	4.44	4.35	4.86	5.19	4.37	2.32	- 8
120	1.63	1.94	2.11	2.02	2.00	2.13	2.30	2.00	1.34	
125	0.77	1.03	1.06	1.04	1.07	1.03	1.11	1.06	0.98	
130	6.24	6.40	6.51	6.46	6.49	6.53	6.64	6.53	6.46	- 9

AP = 4.0 F107 =150.0

DIURNAL AND ZONAL MEAN OF MID-MONTH VALUES

MAY — TEMPERATURE (K)

LAT= KM	-80	-60	-40	-20	0	20	40	60	80 DEG
70	234	233	223	212	208	216	210	220	224
75	229	222	212	200	196	201	193	201	203
80	222	211	205	196	192	191	183	183	184
85	210	205	201	195	192	187	180	173	167
90	198	203	200	191	191	188	183	172	153
95	190	204	198	187	191	192	192	179	163
100	192	204	197	187	192	197	203	194	170
105	207	208	200	196	201	205	214	215	211
110	239	220	214	219	225	223	231	246	273
115	292	253	249	266	266	262	263	272	353
120	364	319	319	342	341	334	334	361	433
125	440	418	420	437	443	440	437	453	486
130	504	497	497	512	526	527	524	534	543

MAY — PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	2.89	3.45	4.33	5.35	5.44	5.66	5.94	6.39	6.83	+ 0
75	1.40	1.66	2.03	2.37	2.38	2.54	2.63	2.89	3.11	
80	0.67	0.77	0.91	1.02	1.01	1.08	1.11	1.21	1.31	
85	3.08	3.44	4.01	4.37	4.24	4.48	4.42	4.22	5.04	- 1
90	1.36	1.52	1.75	1.86	1.78	1.85	1.76	1.79	1.83	
95	5.81	6.79	7.69	7.79	7.55	7.75	7.31	6.95	6.32	- 2
100	2.47	3.06	3.38	3.26	3.23	3.34	3.19	2.89	2.30	
105	1.10	1.41	1.50	1.40	1.42	1.49	1.47	1.30	1.01	
110	5.44	6.70	6.96	6.49	6.67	7.06	7.14	6.45	5.13	- 3
115	3.03	3.46	3.55	3.41	3.51	3.68	3.77	3.57	3.11	
120	1.91	2.03	2.08	2.07	2.12	2.19	2.24	2.21	2.13	
125	1.33	1.36	1.40	1.42	1.45	1.49	1.51	1.52	1.51	
130	0.98	1.00	1.03	1.05	1.08	1.10	1.12	1.12	1.12	

MAY — DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	0.43	0.52	0.66	0.68	0.91	0.91	0.96	1.01	1.06	- 4
75	2.13	2.60	3.34	4.13	4.22	4.41	4.63	5.30	5.33	- 5
80	1.05	1.26	1.55	1.81	1.83	1.98	2.09	2.29	2.49	
85	0.51	0.58	0.69	0.78	0.77	0.83	0.86	0.75	1.05	
90	2.40	2.60	3.04	3.37	3.24	3.41	3.34	3.02	3.95	- 6
95	1.05	1.15	1.34	1.44	1.37	1.40	1.31	1.34	1.37	
100	4.39	5.12	5.87	5.95	5.72	5.81	5.39	5.09	4.57	- 7
105	1.79	2.27	2.52	2.40	2.37	2.45	2.31	2.03	1.61	
110	0.75	1.00	1.07	0.97	0.98	1.04	1.02	0.87	0.63	
115	3.33	4.40	4.55	4.10	4.23	4.53	4.59	3.77	2.83	- 8
120	1.65	2.00	2.03	1.89	1.94	2.07	2.13	1.95	1.55	
125	0.93	1.00	1.01	0.99	1.01	1.05	1.03	1.05	0.90	
130	5.89	6.05	6.18	6.18	6.21	6.37	6.54	6.53	6.43	- 9

JULY — TEMPERATURE (K)

KM	-80	-60	-40	-20	0	20	40	60	80
70	230	227	220	211	211	211	207	215	224
75	220	217	210	200	197	200	193	190	197
80	211	211	204	194	191	196	183	171	174
85	203	208	202	190	188	194	177	161	159
90	196	206	199	187	187	190	181	163	151
95	194	204	196	165	186	166	183	175	154
100	200	201	194	168	190	188	197	176	171
105	217	204	198	200	202	199	213	225	210
110	248	217	215	226	229	226	241	263	280
115	296	252	254	272	277	276	284	313	373
120	362	319	323	345	352	353	353	377	452
125	434	415	418	435	445	447	444	437	490
130	497	490	491	507	522	523	522	531	547

JULY — PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	2.74	3.46	4.30	5.15	5.29	5.31	5.75	7.16	8.30	+ 0
75	1.30	1.63	1.97	2.28	2.34	2.35	2.50	3.23	3.74	
80	0.60	0.74	0.88	0.98	0.99	1.01	1.05	1.23	1.51	
85	2.67	3.35	3.87	4.11	4.12	4.32	4.10	4.79	5.52	- 1
90	1.16	1.50	1.69	1.71	1.70	1.82	1.63	1.50	1.87	
95	4.97	6.73	7.37	7.06	7.05	7.58	6.65	5.77	6.24	- 2
100	2.14	3.02	3.20	2.75	2.95	3.15	2.85	2.45	2.24	
105	1.01	1.36	1.40	1.28	1.29	1.36	1.30	1.13	0.94	
110	5.10	6.41	6.49	6.05	6.12	6.38	6.40	5.53	4.94	- 3
115	2.98	3.29	3.33	3.23	3.28	3.39	3.49	3.25	2.70	
120	1.82	1.93	1.96	1.97	2.01	2.07	2.13	2.12	2.03	
125	1.26	1.29	1.32	1.35	1.38	1.42	1.46	1.47	1.46	
130	0.92	0.94	0.97	0.99	1.02	1.05	1.07	1.09	1.07	

JULY — DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	0.41	0.53	0.64	0.85	0.87	0.87	0.95	1.16	1.27	- 4
75	2.06	2.61	3.28	3.99	4.12	4.10	4.51	5.76	6.62	- 5
80	0.99	1.23	1.50	1.76	1.80	1.80	1.96	2.52	3.02	
85	0.46	0.56	0.67	0.75	0.76	0.78	0.77	0.77	1.21	
90	2.05	2.53	2.95	3.17	3.17	3.33	3.12	3.11	4.31	- 6
95	0.83	1.14	1.30	1.32	1.31	1.41	1.22	1.13	1.40	
100	3.73	5.12	5.63	5.35	5.31	5.74	4.93	4.20	4.47	- 7
105	1.56	2.25	2.38	2.15	2.14	2.30	2.06	1.59	1.51	
110	6.77	7.70	9.92	8.81	9.82	9.30	8.90	7.35	5.71	- 8
115	3.33	4.29	4.22	3.50	3.82	3.77	3.97	3.30	2.50	
120	1.57	1.90	1.93	1.79	1.90	1.84	1.93	1.31	1.42	
125	0.90	0.75	0.97	0.95	0.96	0.99	1.03	1.07	0.92	
130	5.65	5.30	5.92	5.91	5.97	6.16	6.34	6.36	6.20	- 9

JUNE — TEMPERATURE (K)

LAT= KM	-80	-60	-40	-20	0	20	40	60	80 DEG
70	233	233	224	210	207	211	210	217	224
75	225	220	211	197	195	198	192	193	198
80	217	210	204	194	191	192	180	173	175
85	208	204	200	192	191	190	176	162	158
90	199	202	198	189	190	190	179	161	149
95	195	202	195	185	189	191	189	171	151
100	199	202	194	186	192	194	201	190	170
105	213	207	199	197	202	203	218	221	212
110	243	222	217	224	226	224	241	264	268
115	291	256	256	272	272	260	281	320	392
120	338	321	325	347	347	340	348	387	468
125	432	415	418	436	443	441	463	461	495
130	496	488	490	507	522	524	524	534	549

JUNE — PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	2.64	3.34	4.19	5.22	5.25	5.43	6.02	7.25	8.21	+ 0
75	1.27	1.60	1.95	2.30	2.29	2.42	2.63	3.21	3.70	
80	0.59	0.73	0.87	0.98	0.96	1.03	1.07	1.23	1.51	
85	2.71	3.28	3.82	4.13	4.03	4.30	4.17	4.72	5.50	- 1
90	1.19	1.45	1.66	1.73	1.69	1.80	1.63	1.63	1.34	
95	5.17	6.42	7.18	7.19	7.10	7.57	6.64	6.17	6.05	- 2
100	2.26	2.88	3.11	2.99	3.01	3.24	2.86	2.47	2.15	
105	1.04	1.31	1.37	1.29	1.32	1.43	1.32	1.12	0.90	
110	5.19	6.26	6.39	6.04	6.27	6.73	6.34	5.73	4.69	- 3
115	2.90	3.25	3.31	3.22	3.33	3.53	3.56	3.32	2.93	
120	1.82	1.92	1.96	1.97	2.03	2.11	2.16	2.13	2.04	
125	1.25	1.29	1.32	1.35	1.39	1.44	1.47	1.43	1.48	
130	0.92	0.94	0.97	1.00	1.03	1.06	1.08	1.10	1.10	

JUNE — DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	0.39	0.50	0.65	0.87	0.88	0.91	1.00	1.16	1.28	- 4
75	1.77	2.53	3.21	4.05	4.09	4.26	4.75	5.73	6.32	- 5
80	0.75	1.22	1.49	1.76	1.76	1.87	2.07	2.53	3.00	
85	0.45	0.56	0.66	0.75	0.74	0.79	0.82	1.01	1.21	
90	2.08	2.48	2.91	3.18	3.09	3.28	3.16	3.62	4.31	- 6
95	0.91	1.10	1.27	1.34	1.30	1.37	1.22	1.25	1.38	
100	3.08	4.25	5.48	5.48	5.37	5.70	4.36	4.44	4.33	- 7
105	1.63	2.13	2.31	2.19	2.20	2.37	2.04	1.70	1.44	
110	7.02	9.29	9.66	8.86	9.12	9.91	8.97	7.19	5.41	- 8
115	3.21	4.09	4.14	3.78	3.94	4.28	4.10	3.39	2.44	
120	1.60	1.87	1.88	1.77	1.84	1.97	1.98	1.77	1.41	
125	0.70	0.95	0.97	0.95	0.97	1.01	1.04	1.02	0.95	
130	5.63	5.79	5.93	5.94	6.00	6.19	6.39	6.41	6.34	- 9

AUGUST — TEMPERATURE (K)

KM	-80	-60	-40	-20	0	20	40	60	80
70	227	223	219	215	215	218	213	216	225
75	219	216	211	204	201	205	199	194	199
80	213	211	206	198	192	193	189	176	179
85	204	207	203	193	188	194	185	167	165
90	193	205	202	189	185	183	186	170	158
95	187	202	200	186	185	184	190	181	161
100	172	200	198	188	189	185	197	200	177
105	212	203	200	198	201	197	210	223	213
110	253	217	214	221	228	224	233	256	273
115	316	253	249	267	276	274	275	299	354
120	339	322	318	341	352	353	346	364	430
125	451	422	421	437	447	448	441	451	461
130	509	501	500	514	525	524	521	529	542

AUGUST — PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	3.02	3.83	4.43	5.28	5.49	5.46	5.51	6.34	7.03	+ 0
75	1.43	1.79	2.04	2.38	2.46	2.43	2.45	2.80	3.19	
80	0.66	0.82	0.92	1.04	1.05	1.03	1.04	1.13	1.31	
85	2.95	3.68	4.05	4.44	4.39	4.64	4.26	4.25	4.95	- 1
90	1.27	1.64	1.78	1.86	1.81	1.95	1.73	1.50	1.76	
95	5.33	7.32	7.87	7.76	7.42	8.04	7.19	6.13	6.18	- 2
100	2.24	3.26	3.47	3.25	3.09	3.32	3.09	2.59	2.32	
105	1.01	1.47	1.54	1.41	1.35	1.42	1.39	1.21	1.00	
110	5.10	6.87	7.14	6.57	6.39	6.60	6.75	6.13	5.12	- 3
115	2.96	3.53	3.62	3.46	3.42	3.50	3.62	3.49	3.08	
120	1.93	2.07	2.11	2.09	2.10	2.14	2.19	2.17	2.07	
125	1.36	1.39	1.41	1.43	1.45	1.47	1.49	1.47	1.48	
130	1.00	1.02	1.04	1.06	1.08	1.09	1.10	1.13	1.10	

AUGUST — DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	0.46	0.60	0.70	0.86	0.89	0.87	0.90	1.02	1.09	- 4
75	2.27	2.88	3.36	4.06	4.27	4.21	4.29	5.03	5.57	- 5
80	1.08	1.35	1.55	1.83	1.91	1.90	1.91	2.24	2.55	
85	0.50	0.62	0.69	0.80	0.81	0.83	0.80	0.80	1.05	
90	2.30	2.79	3.07	3.42	3.39	3.59	3.25	3.25	3.36	- 6
95	0.99	1.25	1.36	1.44	1.39	1.51	1.31	1.17	1.33	
100	4.00	5.57	6.00	5.90	5.60	6.11	5.35	4.43	4.48	- 7
105	1.60	2.43	2.59	2.38	2.25	2.42	2.23	1.81	1.59	
110	0.66	1.04	1.10	0.97	0.92	0.97	0.96	0.83	0.62	
115	3.31	4.49	4.67	4.16	3.99	4.11	4.26	3.83	2.84	- 8
120	1.36	2.02	2.09	1.92	1.88	1.93	2.01	1.91	1.35	
125	0.93	1.01	1.01	1.00	1.00	1.02	1.05	1.04	0.98	
130	6.00	6.15	6.26	6.23	6.22	6.30	6.30	6.42	6.37	- 9

AP = 4.0 F107 =150.0

DIURNAL AND ZONAL MEAN OF MID-MONTH VALUES

LAT= -80 -60 -40 -20 0 20 40 60 80 DEG

SEPTEMBER TEMPERATURE (K)

KM	-80	-60	-40	-20	0	20	40	60	80
70	225	224	222	216	215	220	215	216	222
75	216	216	213	206	201	206	204	213	203
80	208	206	206	201	192	198	193	179	193
85	196	200	205	199	187	194	194	183	181
90	182	199	207	196	186	190	194	183	174
95	176	201	207	192	187	188	193	190	174
100	183	204	203	190	192	169	193	202	187
105	209	210	200	196	205	199	203	219	217
110	261	224	209	216	231	222	223	246	269
115	338	259	240	259	277	268	264	238	342
120	417	327	310	336	352	345	330	335	410
125	470	432	423	440	449	444	430	435	472
130	526	516	512	522	529	524	510	521	533

SEPTEMBER PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	3.97	4.30	4.81	5.49	5.59	5.57	5.24	5.03	4.73	+ 0
75	1.86	2.01	2.23	2.49	2.50	2.54	2.36	2.27	2.13	
80	0.84	0.91	1.00	1.09	1.07	1.11	1.02	0.97	0.94	
85	3.70	4.00	4.40	4.77	4.44	4.76	4.35	3.95	3.80	- 1
90	1.53	1.74	2.00	2.06	1.83	2.01	1.84	1.59	1.51	
95	6.06	7.61	9.04	8.85	7.56	8.40	7.91	6.52	5.91	- 2
100	2.42	3.41	4.09	3.76	3.20	3.53	3.45	2.33	2.33	
105	1.06	1.56	1.83	1.63	1.42	1.53	1.55	1.31	1.04	
110	5.36	7.48	8.37	7.48	6.83	7.17	7.37	6.60	5.33	- 3
115	3.18	3.90	4.14	3.86	3.69	3.78	3.87	3.66	3.22	
120	2.13	2.30	2.36	2.30	2.27	2.29	2.31	2.26	2.13	
125	1.52	1.55	1.57	1.57	1.57	1.57	1.57	1.55	1.53	
130	1.13	1.15	1.16	1.17	1.17	1.17	1.16	1.15	1.13	

SEPTEMBER DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	6.14	6.67	7.54	8.34	9.08	8.83	8.49	8.39	7.50	- 5
75	2.99	3.25	3.66	4.21	4.35	4.29	4.03	3.89	3.67	
80	1.41	1.54	1.70	1.90	1.94	1.96	1.81	1.77	1.73	
85	6.58	6.97	7.56	8.33	8.25	8.55	7.81	7.51	7.41	- 6
90	2.92	3.03	3.34	3.65	3.41	3.67	3.31	3.01	3.01	
95	1.19	1.31	1.51	1.59	1.40	1.55	1.43	1.19	1.13	
100	4.53	5.70	6.89	6.77	5.68	6.38	5.95	4.79	4.27	- 7
105	1.70	2.50	3.08	2.79	2.32	2.59	2.53	2.01	1.62	
110	0.68	1.10	1.32	1.14	0.97	1.06	1.08	0.89	0.65	
115	3.03	4.86	5.55	4.78	4.27	4.52	4.71	4.11	3.03	- 8
120	1.61	2.22	2.39	2.15	2.02	2.08	2.17	2.02	1.64	
125	1.01	1.11	1.14	1.10	1.07	1.09	1.11	1.09	1.02	
130	6.61	6.76	6.84	6.76	6.69	6.76	6.83	6.75	6.61	- 9

NOVEMBER TEMPERATURE (K)

KM	-80	-60	-40	-20	0	20	40	60	80
70	225	221	217	217	212	215	221	229	230
75	204	202	201	203	199	204	212	220	224
80	184	184	191	197	192	198	207	212	213
85	169	173	189	196	190	195	203	207	207
90	161	174	193	197	190	194	209	207	201
95	164	184	200	196	192	193	203	208	196
100	181	201	205	197	198	195	204	209	203
105	217	223	212	204	211	204	204	213	213
110	277	252	227	223	236	225	215	225	246
115	355	294	261	264	280	268	243	257	296
120	429	360	330	338	352	340	315	322	365
125	483	452	437	442	446	435	413	419	443
130	543	534	524	527	526	512	497	496	504

NOVEMBER PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	7.24	6.70	6.07	5.76	5.49	5.39	4.40	3.08	3.11	+ 0
75	3.32	3.04	2.73	2.60	2.44	2.43	2.00	1.75	1.47	
80	1.40	1.28	1.17	1.13	1.04	1.06	0.93	0.81	0.73	
85	5.42	4.99	4.84	4.34	4.35	4.53	4.17	3.63	3.23	- 1
90	1.96	1.91	2.03	2.08	1.81	1.93	1.83	1.53	1.42	
95	7.04	7.52	8.70	9.00	7.64	8.25	8.54	7.36	6.13	- 2
100	2.70	3.20	3.91	3.92	3.31	3.56	3.83	3.38	2.71	
105	1.18	1.48	1.79	1.74	1.50	1.59	1.77	1.58	1.23	
110	6.11	7.51	8.59	8.19	7.33	7.56	8.23	7.06	6.27	- 3
115	3.64	4.19	4.47	4.27	3.99	4.02	4.23	4.32	3.54	
120	2.47	2.59	2.64	2.56	2.46	2.44	2.45	2.37	2.24	
125	1.76	1.78	1.77	1.74	1.70	1.67	1.61	1.59	1.53	
130	1.31	1.31	1.31	1.29	1.26	1.24	1.21	1.17	1.13	

NOVEMBER DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	1.12	1.06	0.97	0.93	0.90	0.87	0.73	0.56	0.47	- 4
75	[illegible]	5.24	4.73	4.46	4.26	4.16	3.37	2.76	2.32	- 5
80	2.65	2.47	2.12	1.99	1.83	1.86	1.53	1.32	1.12	
85	1.12	1.00	0.87	0.86	0.80	0.81	0.73	0.61	0.53	
90	4.21	3.31	3.64	3.67	3.32	3.46	3.12	2.73	2.43	- 6
95	1.64	1.42	1.51	1.58	1.36	1.48	1.42	1.27	1.07	
100	[illegible]	[illegible]	[illegible]	[illegible]	5.70	6.23	6.47	5.57	4.63	- 7
105	[illegible]	[illegible]	2.89	2.37	2.34	2.61	2.93	2.49	1.93	
110	[illegible]	[illegible]	[illegible]	1.21	1.02	1.10	1.23	1.12	0.93	
115	[illegible]	[illegible]	[illegible]	4.21	4.57	4.79	5.42	4.79	3.93	- 8
120	[illegible]	[illegible]	[illegible]	3.39	2.17	2.27	2.42	2.29	1.93	
125	[illegible]	[illegible]	[illegible]	[illegible]	1.17	1.17	1.17	1.15	1.07	
130	[illegible]	[illegible]	[illegible]	[illegible]	7.27	7.24	7.23	[illegible]	6.91	- 9

LAT= -80 -60 -40 -20 0 20 40 60 80 DEG

OCTOBER TEMPERATURE (K)

KM	-80	-60	-40	-20	0	20	40	60	80
70	226	226	223	218	212	217	217	223	231
75	213	213	209	204	200	205	207	213	222
80	200	198	199	197	193	193	202	207	213
85	184	187	196	196	191	194	201	203	201
90	171	184	200	199	191	193	202	197	189
95	168	187	204	200	193	193	202	193	184
100	179	197	206	200	197	194	202	203	190
105	211	214	207	203	207	202	205	212	212
110	270	241	217	217	229	222	220	233	235
115	335	286	249	253	271	263	235	277	320
120	434	357	318	326	345	337	325	343	394
125	433	449	430	437	446	433	427	436	439
130	540	528	521	526	529	519	538	513	519

OCTOBER PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	5.28	5.31	5.42	5.67	5.57	5.55	4.87	4.11	3.36	+ 0
75	2.47	2.48	2.50	2.57	2.47	2.52	2.22	1.91	1.70	
80	1.10	1.10	1.10	1.12	1.06	1.10	0.98	0.87	0.79	
85	4.59	4.61	4.72	4.79	4.46	4.70	4.29	3.81	3.53	- 1
90	1.79	1.87	2.04	2.07	1.87	2.00	1.88	1.63	1.30	
95	6.70	7.66	9.01	9.07	7.95	8.51	8.31	7.12	6.18	- 2
100	2.59	3.26	4.07	4.01	3.45	3.67	3.71	3.13	2.37	
105	1.12	1.48	1.86	1.80	1.55	1.63	1.69	1.43	1.15	
110	5.71	7.29	8.74	8.37	7.47	7.67	7.74	7.02	5.32	- 3
115	3.44	4.00	4.43	4.28	3.99	4.03	4.10	3.81	3.39	
120	2.33	2.47	2.56	2.51	2.43	2.42	2.42	2.33	2.22	
125	1.68	1.70	1.71	1.70	1.67	1.66	1.64	1.63	1.57	
130	1.25	1.26	1.27	1.26	1.25	1.23	1.21	1.16	1.16	

OCTOBER DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	8.13	8.19	8.47	9.09	9.17	8.90	7.82	6.42	5.36	- 5
75	4.02	4.06	4.17	4.39	4.31	4.28	3.72	3.13	2.67	
80	1.92	1.93	1.93	1.98	1.91	1.94	1.69	1.46	1.29	
85	8.70	8.56	8.36	8.49	8.12	8.41	7.42	6.62	6.11	- 6
90	3.63	3.54	3.54	3.62	3.40	3.59	3.23	2.91	2.75	
95	1.38	1.42	1.52	1.57	1.42	1.52	1.42	1.23	1.16	
100	4.93	5.66	6.76	6.86	5.97	6.43	6.28	5.33	4.32	- 7
105	1.78	2.33	3.02	2.97	2.51	2.69	2.75	2.27	1.32	
110	0.70	1.00	1.32	1.27	1.07	1.13	1.19	0.93	0.75	
115	3.14	4.52	5.74	5.42	4.71	4.89	5.15	4.42	3.41	- 8
120	1.71	2.19	2.54	2.41	2.20	2.24	2.33	2.12	1.77	
125	1.09	1.18	1.23	1.19	1.15	1.15	1.17	1.13	1.06	
130	7.19	7.33	7.38	7.25	7.11	7.12	7.15	7.02	6.84	- 9

DECEMBER TEMPERATURE (K)

KM	-80	-60	-40	-20	0	20	40	60	80
70	225	219	213	215	215	216	220	233	232
75	199	195	195	201	200	202	213	222	225
80	176	174	183	196	194	197	210	214	219
85	159	163	180	194	189	194	210	213	210
90	151	164	186	192	185	191	208	207	202
95	156	177	196	191	184	188	203	205	198
100	176	199	208	193	189	190	199	205	201
105	219	230	220	205	207	202	201	213	215
110	294	268	239	230	241	228	215	226	244
115	371	316	274	277	296	270	251	261	272
120	402	378	340	352	371	350	329	326	359
125	493	458	439	446	452	436	416	417	437
130	550	535	524	525	522	507	470	483	495

DECEMBER PRESSURE (N/M SQ)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	8.04	7.59	6.36	5.77	5.54	5.44	4.55	3.50	2.75	+ 0
75	3.92	3.38	2.81	2.58	2.47	2.45	2.01	1.67	1.42	
80	1.60	1.36	1.16	1.11	1.06	1.03	0.71	0.73	0.67	
85	5.87	5.03	4.67	4.74	4.45	4.53	4.14	3.53	3.07	- 1
90	1.99	1.81	1.86	2.00	1.63	1.91	1.47	1.59	1.37	
95	6.69	6.82	7.81	8.45	7.50	8.02	8.43	7.16	6.00	- 2
100	2.45	2.83	3.47	3.60	3.12	3.33	3.76	3.23	2.65	
105	1.06	1.32	1.67	1.59	1.37	1.43	1.58	1.53	1.22	
110	5.59	6.92	8.03	7.59	6.71	7.07	7.33	7.23	6.16	- 3
115	3.50	4.00	4.31	4.06	3.74	3.81	4.02	3.83	3.47	
120	2.42	2.54	2.58	2.48	2.37	2.35	2.36	2.27	2.18	
125	1.75	1.76	1.75	1.70	1.65	1.62	1.59	1.54	1.41	
130	1.30	1.30	1.28	1.26	1.23	1.19	1.16	1.13	1.11	

DECEMBER DENSITY (KG/M CU)

KM	-80	-60	-40	-20	0	20	40	60	80	
70	1.34	1.21	1.04	0.94	0.90	0.83	0.59	0.53	0.44	- 4
75	6.36	6.04	5.00	4.67	4.30	4.21	3.29	2.62	2.19	- 5
80	3.17	2.73	2.20	1.98	1.91	1.83	1.31	1.20	1.06	
85	1.28	1.07	0.87	0.85	0.82	0.81	0.69	0.57	0.51	
90	4.57	3.83	3.47	3.63	3.34	3.47	3.13	2.82	2.36	- 6
95	1.49	1.33	1.38	1.53	1.41	1.47	1.43	1.20	1.05	
100	4.77	4.87	5.71	6.36	5.62	6.00	6.46	5.40	4.30	- 7
105	1.63	1.94	2.49	2.61	2.23	2.40	2.31	2.37	1.91	
110	0.63	0.86	1.11	1.09	0.92	1.02	1.19	1.03	0.83	
115	2.92	4.14	5.10	4.73	4.06	4.41	5.19	4.70	3.50	- 8
120	1.69	2.16	2.42	2.23	2.00	2.10	2.30	2.17	1.91	
125	1.13	1.22	1.24	1.18	1.13	1.13	1.16	1.13	1.07	
130	7.49	7.58	7.57	7.35	7.13	7.09	7.09	6.91	6.75	- 9

END
7-87
DTIC